MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

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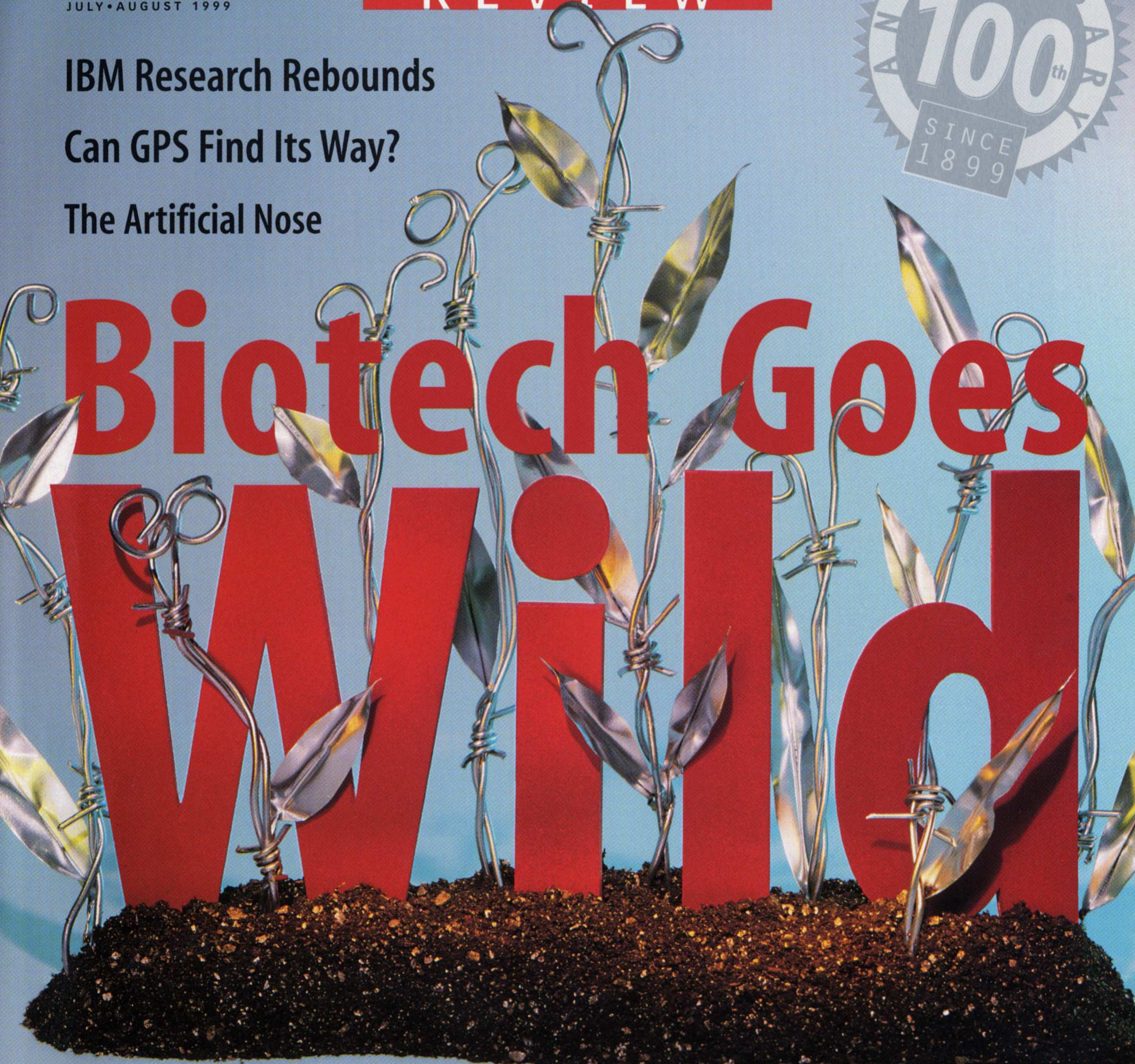
IBM Research Rebounds

Can GPS Find Its Way?

The Artificial Nose



Biotech Goes Wild

Genetic engineering will help feed the world. Will it also unleash a tide of unkillable "superweeds"?

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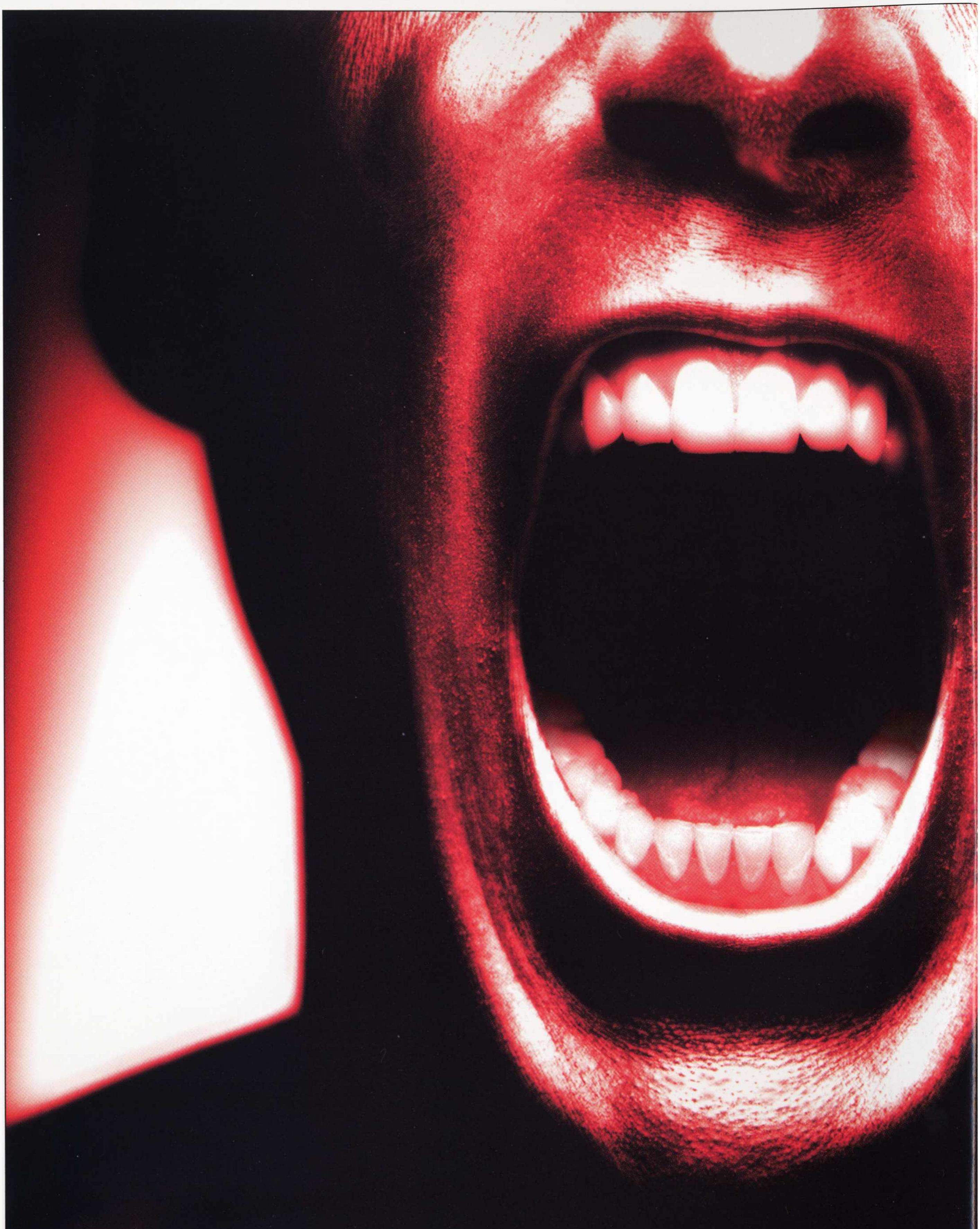
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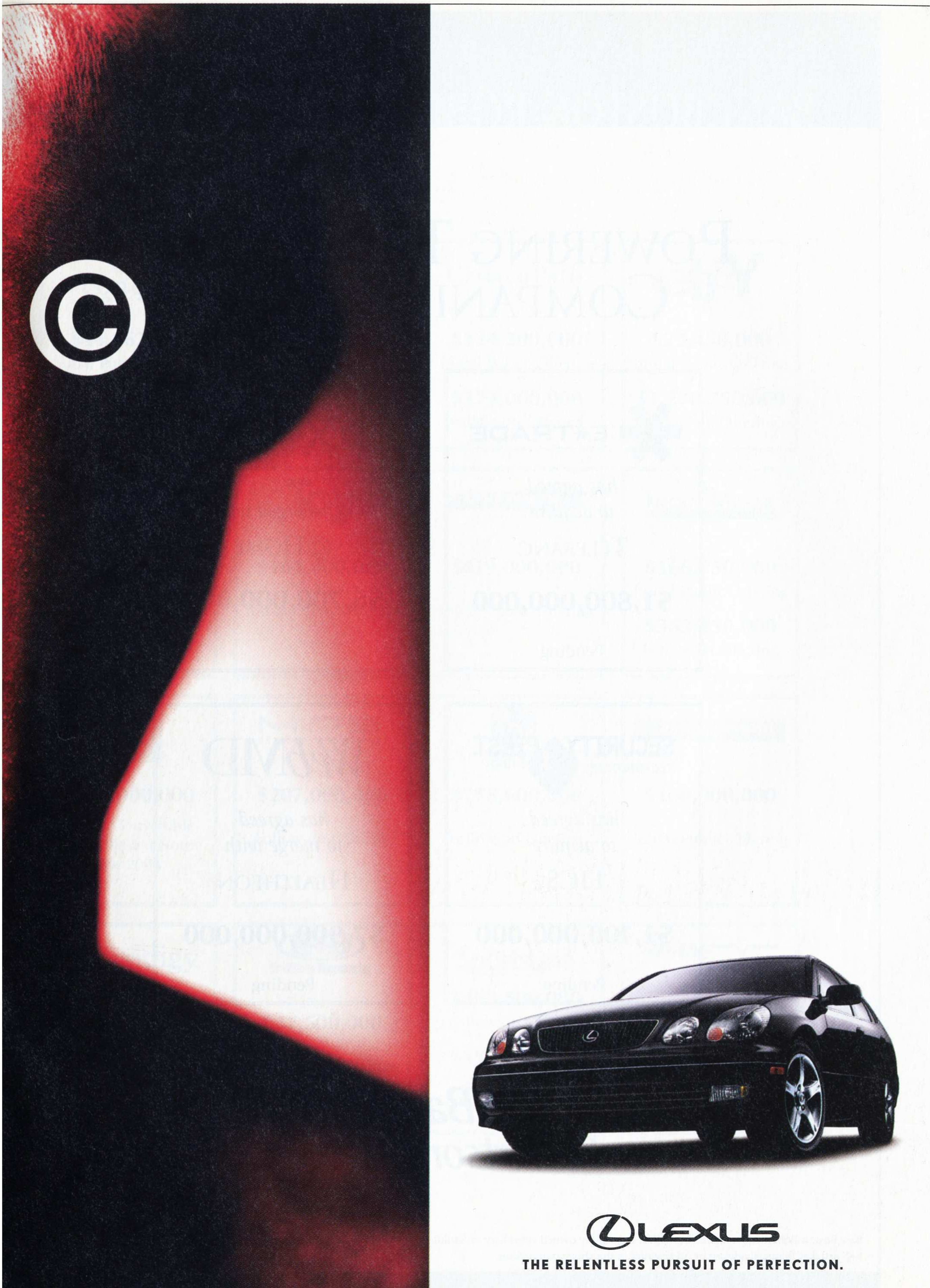
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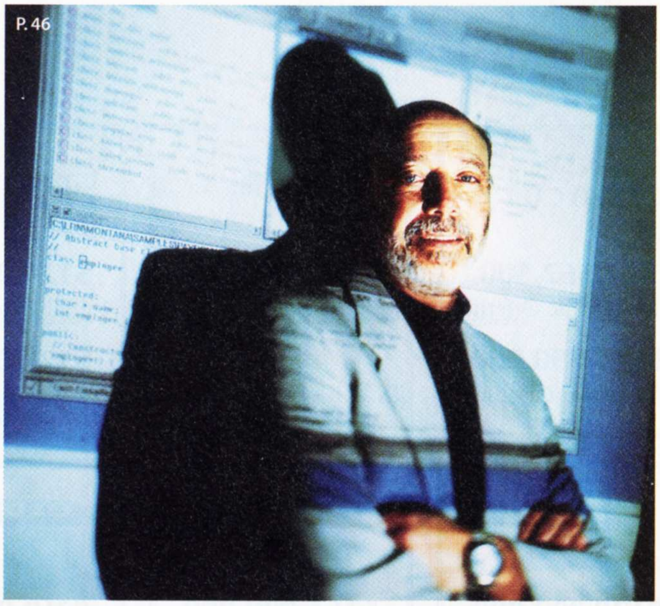
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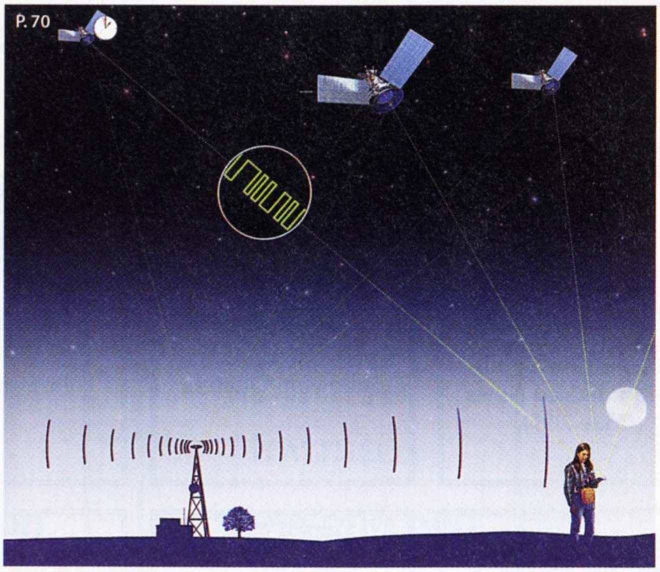
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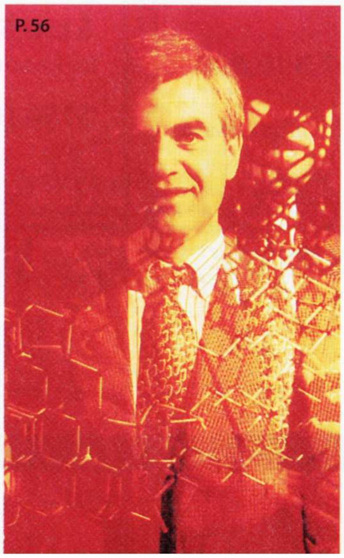
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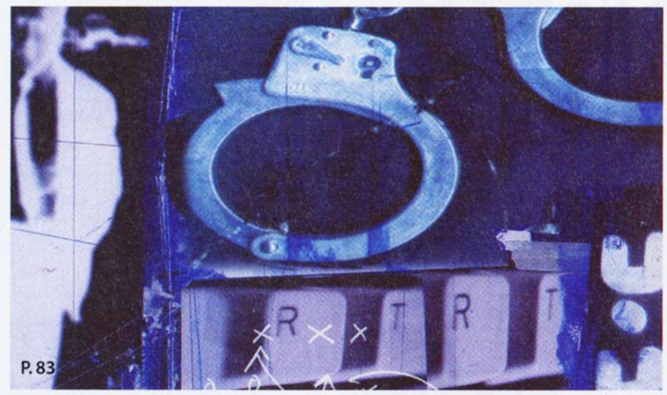
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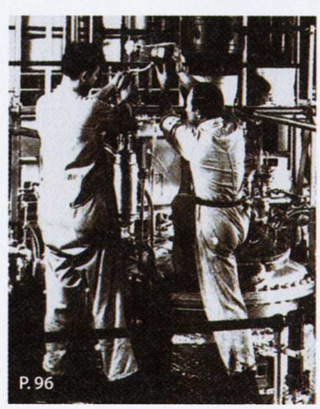
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PEOPLE

ORGANIZATIONS

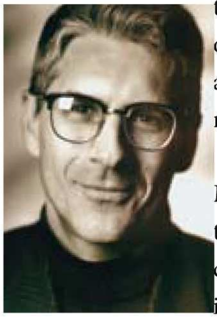
Food Fight

Agricultural biotechnology seems to attract a lot of attention these days. Unfortunately, most of it is the wrong kind.

The genetic engineering of plants will almost certainly be needed to feed a human population that will stabilize at 10 billion or more sometime during the next century. Furthermore, it's the first arena where the techniques of genetic manipulation, developed during the 1970s, are being applied on a large scale. Therefore, the attention is justified, since we need to be mindful of what we as a species are doing to the other species on the planet when we modify the genes of our food crops.

The problem is that the debate on this topic seems to have been hijacked by extremists on both sides: environmentalists crying disaster and corporate spokespersons telling us soothingly that there's nothing to worry about—that there's nothing sinister or even unusual about genetic engineering, which, they argue, simply extends methods farmers have used since the beginning of agriculture to improve crops and livestock.

Both extremes are wrong. Certainly global disaster isn't just around the corner. On the other hand, there *is* something novel and extraordinary about our ability to insert the genes of one species among the genes of another. And, as with the introduction of any remarkable new technology, unforeseen consequences are inevitable.



One possible consequence is addressed in detail by Charles C. Mann in this issue's cover story, "Biotech Goes Wild." Mann, one of the nation's very best science and technology journalists, reveals that crops genetically engineered to produce or resist pesticides could interbreed with wild plants, giving rise to "superweeds" that could be very hard to eradicate and might choke food crops. Many biologists have dismissed the threat of such phyto-promiscuity, but some scattered data are unsettling. And the fact is that science can't yet tell us whether to be alarmed.

Why are we still in ignorance on this important issue? One reason is that the biologists who engineer genes into plants aren't trained to think about the whole organism and its habitat; they're molecular folk, lacking an ecological perspective.

Another reason is the patchwork of U.S. regulatory agencies that govern agricultural biotech: the Food and Drug Administration (FDA), the Environmental Protection Agency (EPA), and the Department of Agriculture (USDA). Mann writes that none of these agencies is responsible for superweeds, which could grow between the bureaucratic cracks. The FDA doesn't look at plants engineered to express pesticides, because pesticides are exempt from the agency's reach. The EPA is required to treat such foods as pesticides and simply establish human tolerances for each compound. USDA tries to make sure the crop grows as the producer says it will.

There's only one thing omitted from this patchwork: the public interest. To stitch it back in two things are needed. One is additional research, from biotech companies and the federal government on the ecological consequences of genetic engineering. The other is a revision of the regulatory framework to make at least one of the agencies responsible for testing the environmental consequences of agribiotech. These changes would acknowledge the growing impact of this remarkable new technology and help us steer a course between wrongheaded extremes.

—John Benditt

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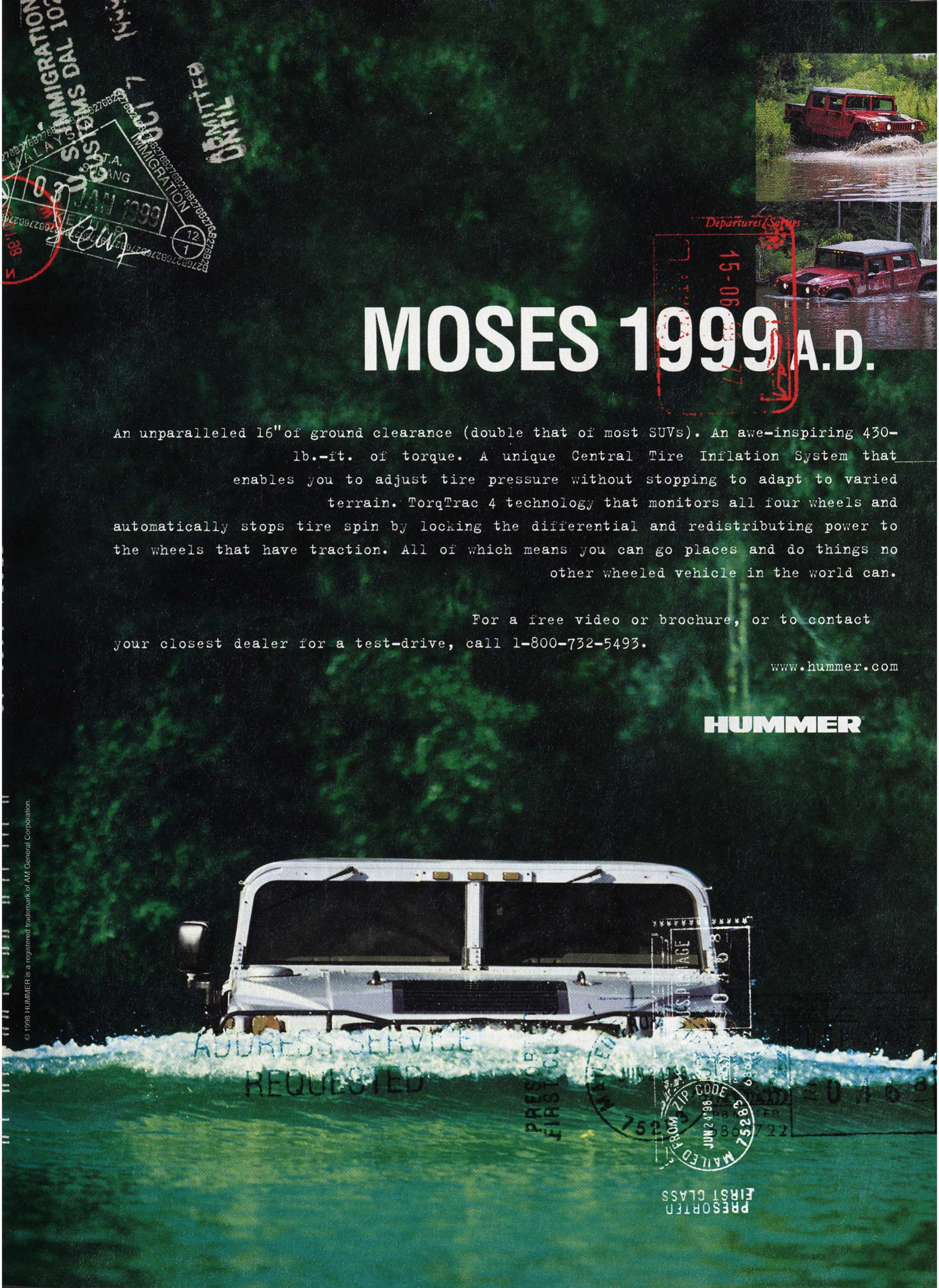

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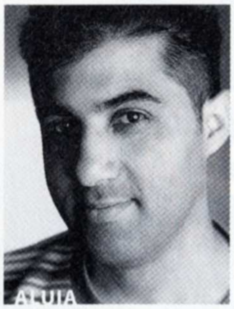
In this column we most often celebrate *TR*'s writers. But we're also proud of the folks who provide the visual setting in which the words appear. This issue, we'd like to brag a little bit about our artists before "reverting to type." | They say that the clothes make the man. Does the cover make a magazine? In every issue of *TR*, it is art director **Kelly McMurray's** job to come up with a design for the magazine's frontispiece. This issue's top story, "Biotech Goes Wild," an analysis of agricultural biotechnology written by contributor **Charles C. Mann,** gave McMurray inspiration for a cover image that would depict both the indestructible superweeds that genetic engineering may engender as well as the blurring of human-made and natural worlds. To create the cover art McMurray called on **Vito Aluia,** a Cambridge, Mass. artist who builds and photographs surrealistic scenes of Lilliputian proportions. The image he created for our cover is a close-up photograph of a stage set 25 centimeters across, constructed from foam letters and adorned with weeds made of barbed wire and sheet metal. The benefit of such small objects, says Aluia, "is the quality of the light you can get." He bathed the mock-up with a dim blue light, and exposed his film for nearly a minute as he "painted on" color highlights using green and yellow flashlights. The outcome is Aluia's signature visual hybrid, a recombinant image of real and unreal elements. Aluia's provocative dioramas appear regularly in *TR*'s Prototype department. He can often be found at hobby shops buying components for his tiny worlds. | **Silvia Otte** also deserves laurels for portraits appearing in "Into the Big Blue Yonder" on p. 46. The German-born photographer says she enjoys shooting technologists because "It's a way to get behind the scenes into off-limits, sci-fi places." True, IBM's Thomas J. Watson research lab isn't quite material for an episode of "The X-Files," but Otte's fascination with technology's setting allows her to create photographs that evince her subjects' irresistible connections to their workspaces. Otte's work has appeared in *The New York Times Magazine*, *Mademoiselle* and *Details*. She emigrated to the United States from Hamburg in 1989 and lives on Manhattan's lower East Side. | We can't end Voices without talking a bit about two of our writers. One is **Ilan Greenberg,** who traveled from his home in San Francisco to Pasadena, Calif. to visit Cyrano Sciences, an aptly named startup that is looking to sell a new instrument for detecting and assessing odors. Greenberg, a first-time contributor to *TR*, has been on the staff of *InfoWorld* and *PC Computing*, and now freelances for publications such as *Wired*, *Business 2.0* and *US News & World Report*. | Freelancer **Claire Tristram,** who wrote about IBM's hard-disk wizards in the July/August 1998 issue of *TR*, returns to our pages with an update on the Global Positioning System. Her reporting, she says, brought to mind her first job out of college—overseeing a phone company switchboard—in which women twice her age had to ask her permission to use the bathroom. Tristram was troubled by this tyranny of the time-clock, and in "Has GPS Lost Its Way?" she explores what it could mean for employees if bosses know their exact latitude and longitude, even when they're out of the office. TR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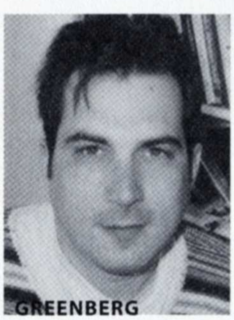
OTTE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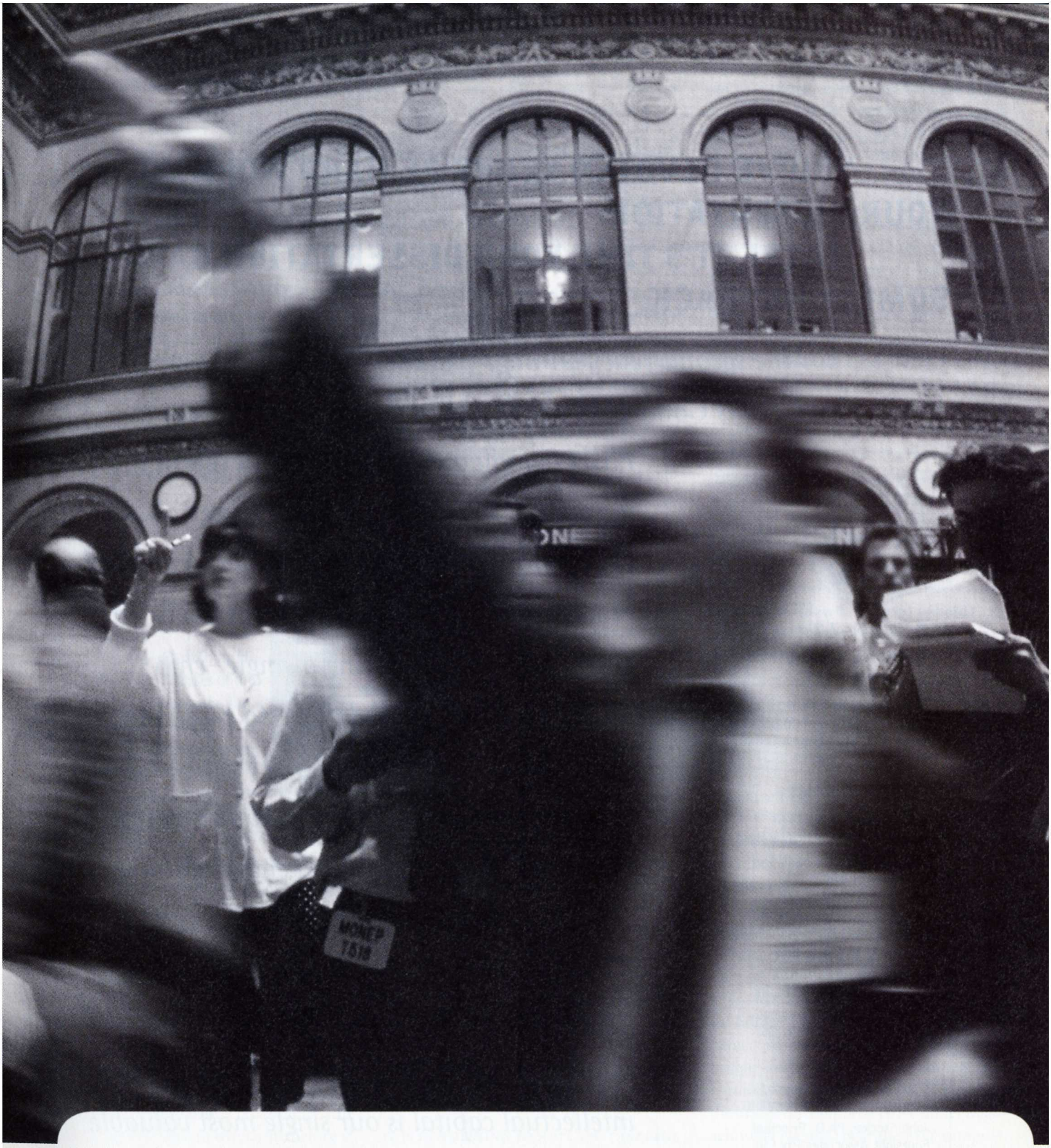
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For the second year running, The Merrill Lynch Forum Innovation Grants Competition will award $150,000 to recent Ph.D. candidates who can best explain the marketplace potential of their dissertation. Last year's first-place winner, Dr. Jan Mark Noworolski of UC Berkeley, was awarded $50,000 for proposing a single-chip power converter. In addition to receiving cash awards, winners will meet with leading entrepreneurs and venture capitalists to discuss their work. Applications and entry information can be obtained from The Merrill Lynch Forum website at www.ml.com/innovation.

The Merrill Lynch Forum is a "virtual" think tank predicated on the idea that human intellectual capital is our single most valuable currency. It brings together leading thinkers to consider issues of worldwide importance in technology, economics and geopolitics.

The independent panel of distinguished scientists and entrepreneurs judging the competition, under the direction of Michael Schrage, Research Associate of the MIT Media Lab, will include:

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HUMAN ACHIEVEMENT

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"Most press accounts leave the impression that the artificial retina will be available soon. I applaud your balanced coverage."

Upload Me, Scotty

THANKS FOR PUBLISHING THE ARTICLE ON Steve Mann's quest to put himself into cyberspace ("Cyborg Seeks Community," *TR* May/June 1999). As someone putting all my cyberizable past (books, papers, videos, photos and whatever) in cyberspace, it gave a nice glimpse of how far we can go to really be there. I'm trying.

GORDON BELL
Senior Researcher, Microsoft
Los Altos, CA

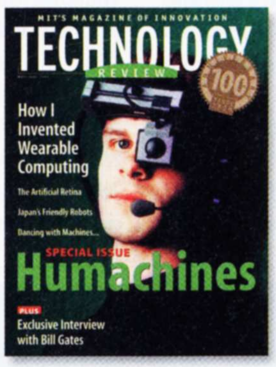
Balanced Vision

AS A VISION SCIENTIST WHO directs medical research funding for blinding diseases of the retina, I was pleasantly surprised by Victor Chase's article on research to develop a bionic retinal prosthesis ("Seeing is Believing," *TR* May/June 1999). Such a device represents a promising research avenue to restore lost vision to the millions of people who are affected by blinding retinal degenerative diseases. For this reason, the patient community pays very close attention to media coverage of the retinal prosthesis. Unfortunately, most press accounts leave the mistaken impression that this high-tech device will be available in the near future. Such coverage instills a false sense of expectation and hope in patients who desperately desire sight-restoring treatments. However, your coverage made clear that this technology still has several hurdles to overcome before it becomes a reality for patients. I applaud your balanced coverage of this research effort.

DR. GERALD CHADER
Chief Scientific Officer
The Foundation Fighting Blindness

Get the Bugs Out!

MICHAEL DERTOUZOS' AND BILL GATES' dialogue about the future of software ("Titans Talk Tech," *TR* May/June 1999) failed to address, or even mention, the number-one unsolved problem in personal computing: Software from Microsoft (and most everywhere) is riddled with bugs that cause errors and system crashes on a regular basis. Program understanding, a painful but necessary step in fixing bugs, costs perhaps $200 billion per year in business systems. Consumers are not, in general, programmers, so the bugs never get fixed. Gates rhapsodizes that consumers get "an amazing amount of functionality...at a very low cost" but is curiously unapologetic about the abysmal quality of that software. True, the purchase price of Windows 95 is very modest. However, the dysfunctional flaws, present by the tens of thousands in Windows 95, are a constant source of frustration, wasted time and huge unaudited costs borne by regular users, who also know that there is really nothing to be done. The manuals and built-in trouble-shooting help files are incomprehensible and don't begin to address the bulk of embedded bugs that were present when the program was shipped. It remains to be seen when, or even if, any real productivity gains will ever be demonstrable as a result of the use of these very expensive toys.



ALAN ENGLISH
English Enterprises
Summit, NJ

IT IS INTERESTING TO NOTE THAT ON PAGE 78 of the May/June issue of *TR*, Bill Gates is quoted as stating: "...no matter how good PCs get at recognizing voice or handwriting, they'll never read body language or smile back at you." But a mere 15 pages before his quote is an article about robots in Japan that already do exactly that! Perhaps someone ought to send him a copy of that article?

NANCY MILLER
Pittsburgh, PA

We welcome letters to the editor.
Write: *Technology Review*, Building W59, Cambridge, MA 02139. Fax: (617)258-8778. E-mail: <technology-review-letters@mit.edu>. Please include your address, telephone number, and e-mail address.
Letters may be edited for clarity and length.

BILL GATES' COMMENTS MAKE IT CLEAR that the average office worker's frustration with computer software will continue for the foreseeable future. The main computer tasks performed by most office workers with inexpensive commercial software (word processing, spreadsheet, file management) have not changed much in the last decade, nor have the basic capabilities of the software. Meanwhile, we have been forced by the market to relearn these tasks numerous times as software changes—and buy expensive new computers every few years, too. Mr. Gates' vision of automatic upgrades occurring while we sleep is the average office worker's nightmare: to wake up and find our software has changed so what we knew how to do yesterday we don't know how to do today. Many of us are resisting computer "upgrades" until the computer industry changes its ways.

DAVID K. SWANSON
Fairbanks, AK

Early Warning

AS I WAS READING THE ARTICLE ABOUT THE Bridge Bash Monitor ("Blimey Bash," *TR* May/June 1999) it occurred to me that what is needed is a warning system. Why wait until an accident has happened? Why not a system to monitor the height of oncoming vehicles and present visual warnings, or even an audible warning, when a vehicle approaches that is too high to pass under the bridge? There are currently systems that hang cords and have signs warning of low bridge clearances, but these are regularly ignored—for example at the entrance to the bridge on Memorial Drive under Massachusetts Avenue (near the MIT campus).

KEN GEORGE
Winchester, MA

Heartburn

THE TONE OF ANTONIO REGALADO'S ARTICLE discussing recent work in the development of an artificial heart ("CPR for the Artificial Heart," *TR* May/June 1999) disturbed me. Regalado seems to believe the only use for an artificial heart would be to

keep a patient alive while waiting for a transplant. He ignores one of the key reasons why research in this area is so important: There will *never* be a sufficient number of compatible donated organs available to meet the demand for transplants. As things stand now, a patient with a diseased heart must wait weeks, months, sometimes years for a compatible donor organ to become available while being placed in the macabre situation of having to hope for someone else to die in order to prolong her own life. If the Jarvik-7 was Dracula, today's system of organ transplants turns surgeons into Dr. Frankensteins ghoulishly forced to solicit spare parts from grieving relatives. The quest for human organs is already raising disturbing questions among bioethicists as suggestions are occasionally put forth to "compensate" family members for loved ones' livers, hearts, lungs and other parts in order to help sway the bereaveds' opinions regarding donation.

While it is true William Schroeder experienced numerous devastating side effects following the implantation of the Jarvik-7, it is important to remember his quality of life would not have been perfect had he undergone a conventional heart transplant rather than volunteering to participate in the experiment with the Jarvik-7. In addition to blood clots and stroke being common potential side effects of all surgeries, every transplant recipient is condemned to spend the remainder of his or her life on a regimen of expensive antirejection medications, which, as we all know, are not always effective. The media, *TR* included, has been guilty of painting a much rosier picture of transplant surgery than it may merit. Although both the survival rates and the overall quality of life for transplant patients have improved dramatically in the past 20 years, the procedure still involves significant risks. In short, the reality is that if and when an artificial heart becomes available for use in humans, patients receiving such a device will indeed be facing different possible complications and side effects than transplant patients, but whether those various risks will be greater than those currently involved in transplant surgery is debatable.

NANCY FARM MANNIKKO
Visiting Assistant Professor
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University of Minnesota
Minneapolis, MN

Don't Knock Nukes!

FAR FROM BEING ON THE TECHNOLOGICAL junk heap with the Jarvik heart and supersonic planes as Associate Editor Antonio Regalado states in "CPR for the Artificial Heart" (*TR* May/June 1999), more than 100 nuclear power plants are presently supplying more than 20 percent of central station electricity. Efforts to educate the public on the benefits of nuclear power are seriously impaired when responsible publications like *Technology Review* publish such misinformation. The principal reason for the lack of new orders for nuclear power plants is economic. We continue to burn coal and gas because they are cheaper, even though they are major contributors to air pollution, acid rain and global warming. It also isn't well known that many coal-fired power plants would have to be shut down if the radiation release limits imposed by the EPA on nuclear power plants were applied to them.

PETER J. DAVIS
Paris, VA

STEPHEN HALL'S "MISSING THE STORY" (*TR* May/June 1999) struck a chord with me, and I'm sure with other technologists. How

can the media, which presume to inform us and explain to us the significance of all that goes on, completely miss out on some of the most important events in history—those that involve technology?

I recall a 1952 news story headlined "That $40 Billion Again." The story told how Truman took a crack at a presidential candidate who claimed he could save $40 billion by running the country better. Only the phrase, "speaking at the launching of the first atomic submarine..." told readers that the real story was the first large-scale use of controlled nuclear fission, certainly one of the most significant steps in human development.

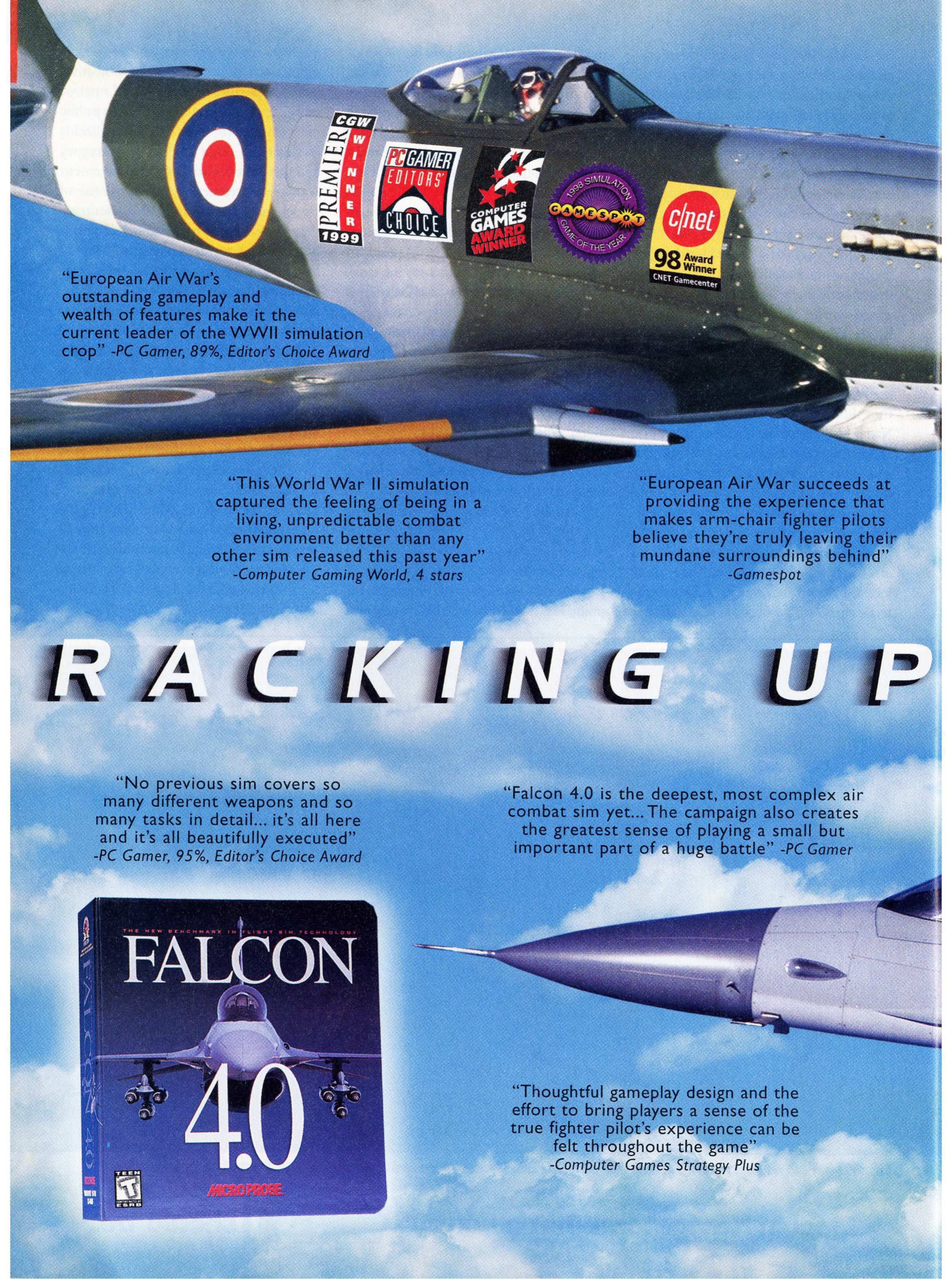
We tend to blame this situation on the media, and scorn the technical illiteracy of the public. But Jane Fonda and Ralph Nader didn't invent the idea that one gamma ray can kill you, and that you can add up trivial radiation doses to "predict" deaths in an irradiated population. Those ideas, which no technical person takes seriously, were nonetheless created by technologists anxious to prove they could meet any standard—just name it. These ideas have since been engraved in radiation protection policy. They have created lucrative study projects describing how hundreds of thousands of years after radioactive waste is buried, some lone atoms will diffuse through miles of desert soil to create a health hazard. The public would be foolish not to fear such a threat. And we technologists created this fear; the media just pass it on.

For confirmation, we have only to turn to "CPR for the Artificial Heart." Regalado writes that the artificial heart program was relegated to the "short list of technologies American society has labeled 'Just Not Worth It'...alongside supersonic airplanes and nuclear power plants." Don't you guys read the news? Nuclear power generates more electricity in America than any other source except coal—more than oil, gas, hydro, or the elusive "renewables." And it has been doing this for 40 years, reliably, economically, safely, and with virtually no impact on the environment or on human health.

THEODORE ROCKWELL
Chevy Chase, MD

The editors respond:
Davis and Rockwell seem to be missing the point. Regalado's article (which mentioned nuclear energy in only one sentence) didn't say anything about the objective, technical virtues—or faults—of nuclear power. It simply said the American public in its wisdom (or lack thereof) has decided this technology falls into the category of "Just Not Worth It." The statement seems incontrovertible. While the use of nuclear power expands in other countries, there are currently no new nuclear power plants under construction in the United States. Although economics may play a role in this situation, public opinion of the NIMBY ("not in my back yard") variety is clearly also a major contributor. The last nuclear power reactor to go online in the United States was the Wattsbar plant near Spring City, Tenn. Construction began in the 1970s, but because of strong local opposition and safety concerns the plant did not begin operating until May 27, 1996.

Davis is correct when he says that nuclear power accounts for 20 percent of U.S. electricity production. This figure ranks the United States 20th among the 32 nations that use nuclear power, behind Bulgaria (where 42 percent of power production is nuclear), as well as Lithuania (77 percent) and Spain (32 percent).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COMPUTER GAMES AWARD WINNER
1998 SIMULATION GAMESPOT GAME OF THE YEAR
c|net 98 Award Winner CNET Gamecenter
"European Air War's outstanding gameplay and wealth of features make it the current leader of the WWII simulation crop" -PC Gamer, 89%, Editor's Choice Award
"This World War II simulation captured the feeling of being in a living, unpredictable combat environment better than any other sim released this past year" -Computer Gaming World, 4 stars
"European Air War succeeds at providing the experience that makes arm-chair fighter pilots believe they're truly leaving their mundane surroundings behind" -Gamespot
RACKING UP
"No previous sim covers so many different weapons and so many tasks in detail... it's all here and it's all beautifully executed" -PC Gamer, 95%, Editor's Choice Award
"Falcon 4.0 is the deepest, most complex air combat sim yet... The campaign also creates the greatest sense of playing a small but important part of a huge battle" -PC Gamer
THE NEW BENCHMARK IN FLIGHT SIM TECHNOLOGY
FALCON
4.0
MICROPROSE
TEEN
"Thoughtful gameplay design and the effort to bring players a sense of the true fighter pilot's experience can be felt throughout the game" -Computer Games Strategy Plus


EUROPEAN
AIR WAR
20 FLYABLE PLANES!
MICROPROSE
"The care and attention to detail that went into every aspect of European Air War, from the hefty manual to the bomber nose art, represents a serious achievement"
-CNET GameCenter
"European Air War combined huge dog fights, a great campaign system and realistic physics to make a game that was very hard to put down"
-IGN PC.com, Sim of the Year
THE KILLS!
"Bottom line: this sets the new standard in flight sims"
-Washington Post
"Falcon 4.0 is an incredibly detailed simulation that in many ways exceeds training systems in military use."
-Computer Gaming World
PC GAMER
ANNUAL AWARDS
BEST SIMULATION
1999
PREMIER
FINALIST
1999
Award of Excellence
FlightSim
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Ad Attack

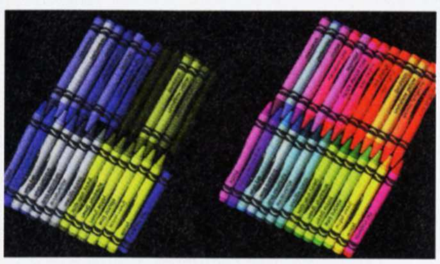
Web users waiting for pages to load find their days filled with innumerable small delays—long enough to break the rhythm, but too short to do other work. These moments represent prime real estate to Internet marketeers, who see the gaps as a perfect opportunity to squeeze in a commercial message. That's the logic behind "webmercials"—a new form of advertising that should begin appearing in the coming months. KMGI.com, a New York ad agency, is creating eye-popping animations that appear on the screen during gaps in an online session. The webmercials use vector graphics, which describe an image with succinct mathematics rather than specifying each pixel. Thus tiny files—typically 25 kilobytes—can deliver audiovisual spots lasting 5 to 7 seconds.

WEBB CHAPPELL

Chunks of wood as computer interface.

Playing With Blocks

Brygg Ullmer, a researcher at MIT's Media Lab, thinks that we shouldn't have to deal with a computer screen to get networked multimedia devices to work together. If Ullmer gets his way, we'll be able to use wooden blocks. The "mediaBlocks" would serve as a simple means to copy recorded information from devices such as video cameras and whiteboards, and paste it into an output device like a video projector or a laser printer. For instance, inserting a mediaBlock into a slot on a digital whiteboard—a collaborative writing surface whose contents are stored electronically—would copy its contents onto a network computer and simultaneously write a code onto the block specifying the file's location. Inserting this mediaBlock into a printer would retrieve the file and produce hard copy of the writing on the whiteboard—all without requiring a conventional screen interface. Arranging these blocks on a Scrabble™-like rack would allow manual sequencing of multimedia elements.



JAY NEITZ

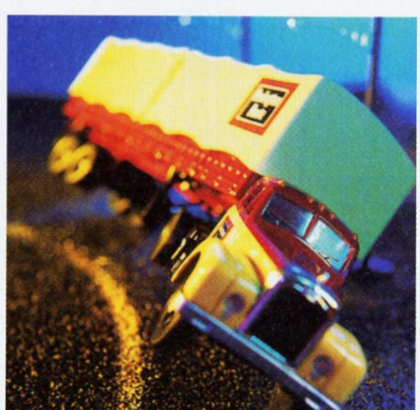
Spotting the spectrally challenged.

Rainbow Remedy

Kindergarteners are expected to know their hues—they use them to complete innumerable color-coded lessons. This makes life a challenge for children who cannot distinguish between certain colors. A husband-and-wife team at the Eye Institute of the Medical College of Wisconsin in Milwaukee is developing a two-part screening program to better identify these children.

Standard color-vision testing requires one-on-one consultation with an expert. Researchers Jay and Maureen Neitz devised an inexpensive, paper-and-pencil test that kids can take in minutes and that teachers can easily score. Then, by running a simple DNA test on cheek swabs from kids who test abnormally, the Neitzes detect genetic patterns that correspond to the nature of each child's impairment. The researchers have licensed the paper exam to Western Psychological Services, a California test publisher; they don't have a partner for the genetic component of the screening.

Keep on Rollin'



VITO ALUIA

A system of sensors and computers that alerts truck drivers when their rigs are in danger of rolling over could prevent as many as 4,000 accidents a year, according to researchers at Oak Ridge National Laboratory (ORNL). The rollover detector developed at ORNL consists of sensors in the trailer that measure the weight transfer at the rear axle and the lateral acceleration; that information is fed to an onboard computer that tracks in real time the truck's stability. In addition, the ORNL researchers have positioned at several curves roadside beacons that alert the approaching trucks. If the vehicle is in danger of rolling over, a warning sounds for the driver to slow down. The lab has equipped several trucks owned by U. S. Xpress Enterprises with the system, which costs about $7,000 for each tractor-trailer. The trucks are to begin testing it this summer as they rumble up and down Interstate 75.

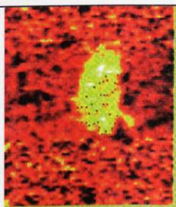
Liquid Glow

Light-emitting polymer (LEP) displays are attractive to electronic gadget makers because the plastics glow brightly and use little power. But fabricating a polymer layer a mere micrometer thick can be expensive. A Santa Barbara, Calif., startup, Uniax, has patented an easier and cheaper way to manufacture LEP displays. Uniax first dissolves the LEPs in a common organic solvent, then deposits the solution directly onto the substrate.

Uniax is initially targeting monochrome displays for handheld units such as cell phones and pagers. The company says it has built prototypes and expects companies to start testing LEP-endowed products by year's end.

UNIAX

Recipe for a display.



MAX PLANCK INSTITUTE

2-by-2 micrometer nanoview.

Nanoscope

Specialized microscopes that can image individual atoms have opened up the nanometer-scaled world to scientists. But existing scanning probe microscopes, which move an extremely fine tip along a surface, are able only to map the topography of the atomic world; they cannot easily distinguish between different compounds.

To overcome this chemical blindness, scientists at Max Planck Institute in Martinsried, Germany, have built a scanning microscope able to perform infrared (IR) spectroscopy—a common analytical technique that exploits the characteristic IR absorption of different compounds. The tip of the microscope is positioned just above the sample and is illuminated by an infrared beam; the tip then senses the IR absorption of the sample beneath it. The Max Planck researchers have identified different polymers with a resolution of 100 nanometers, and hope to achieve resolution as fine as 10 nanometers.

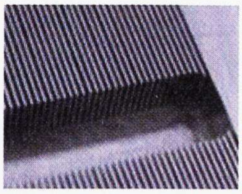
VITO ALUIA

Swifter Shopping

Despite all the hoopla, buying stuff online can be a nuisance. Filling out order forms with personal information, product selection, shipping preferences and so forth is not quite the painless experience that many envision. QuickBuy, a Tyngsboro, Mass., startup, is about to introduce software that will enable consumers to do one-step shopping on the Web.

Online merchants using QuickBuy's software will display their wares as "buycons"—graphical icons that are embedded with a product's price and a detailed description. A consumer using Quickbuy's free software simply drags a buycon onto a transaction icon that's programmed with a credit card number and shipping address. The software lets a shopper fill a shopping cart with goods from numerous online stores and check out in one step. QuickBuy will pilot test the software in July and expects commercial rollout in October.

Carry-on Cooler



PNL

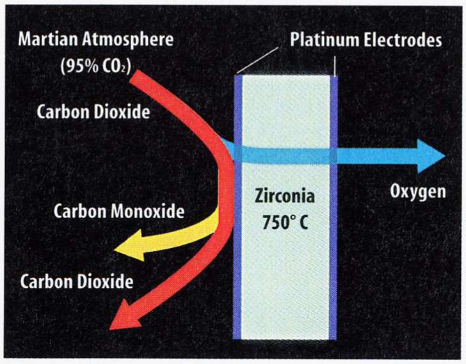
Tiny heat-pump structures.

Soldiers, firefighters and others who risk exposure to hazardous materials must wear hot, heavy protective clothing for prolonged periods. Research at the Department of Energy's Pacific Northwest National Laboratory (PNL) in Richland, Wash., is leading to a small, lightweight heat pump that could be worn inside such garments to provide hours of cooling relief.

Heat pumps use the condensation-evaporation cycle of a working fluid to move heat from one place to another. The PNL device mechanically constrains the fluid to microchannels in a film only about 100 micrometers thick—10 times thinner than in conventional heat pumps. The thin film maximizes the surface-to-volume ratio and hence the efficiency of heat transfer between the fluid and the environment, says PNL researcher Michele Friedrich. Based on tests of the individual components, Friedrich believes it will be possible to build a prototype of a portable heat pump weighing only about 5 kilograms.

Fresh Air for Mars

NASA engineers have developed a system to extract oxygen from thin air—thin Martian air, that is. The device could provide breathable air and rocket-fuel oxidant for voyagers to the planet, where the atmosphere is primarily carbon dioxide. CO_2 is fed into a zirconia disk that is heated to 750° C and sandwiched between platinum electrodes. The zirconia chemically breaks the CO_2 into oxygen and carbon monoxide. The oxygen filters through the zirconia and is collected; the carbon monoxide cannot pass through the disk. NASA has demonstrated this "oxygen pump" under simulated Martian conditions at the Johnson Space Center, according to principal investigator David Kaplan. A real test will come when the device is included on the next Mars lander mission, scheduled for launch in April 2001. If it works, the system would help lower the mass and cost of future missions.

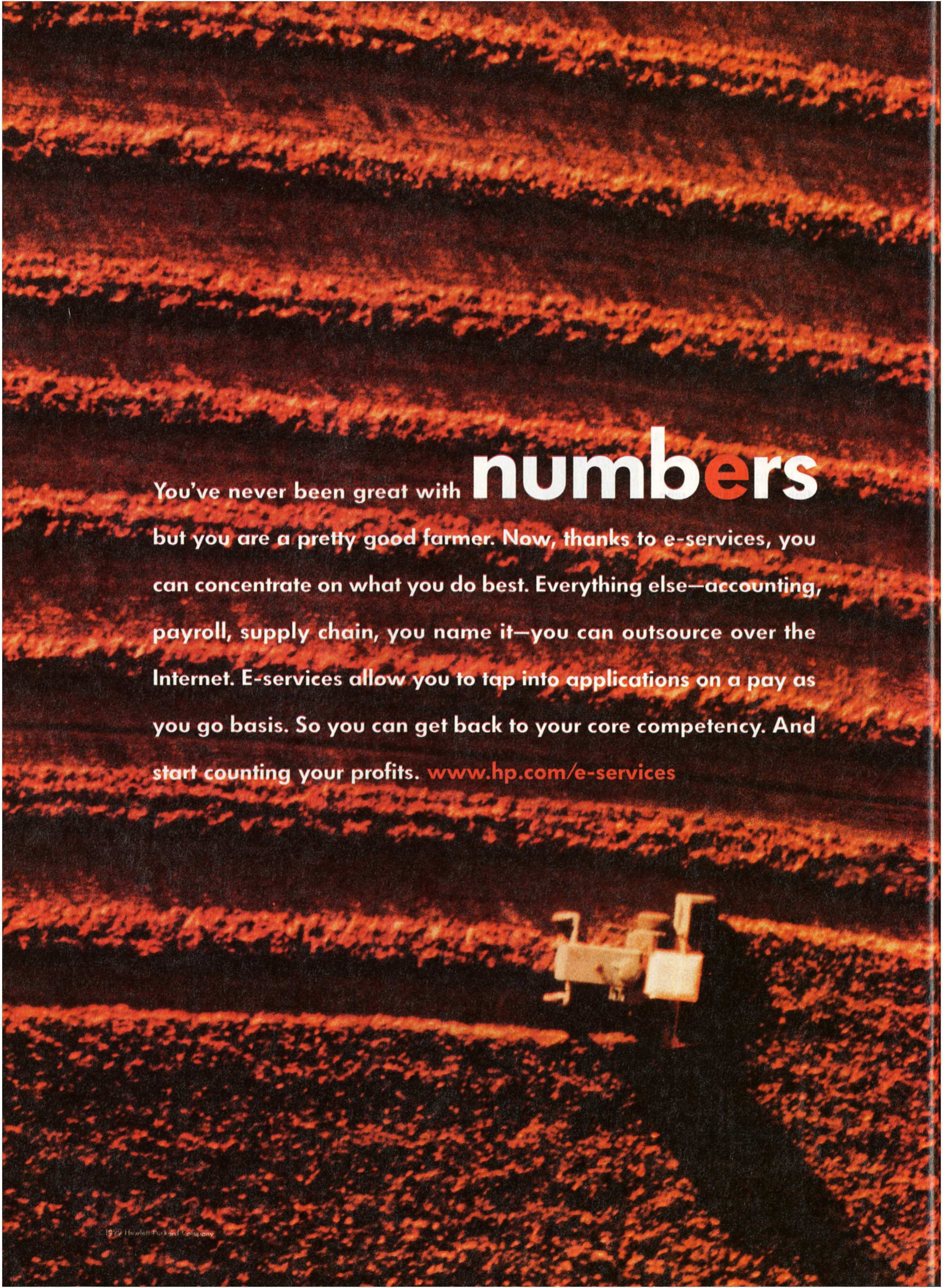


BETSY HAYES; SOURCE: NASA

The Inside Touch

In minimally invasive surgery, doctors operate through punctures in a patient's skin. A long-handled camera called an endoscope snaked into the body lets surgeons see what they're doing.

Looking to add the sense of touch to these peephole procedures, MIT bioengineering student Jonathan Thierman invented an endoscope that can "feel" anatomical structures. A water-filled rubber membrane on the tip of a probe deforms when pressed against tissue. Changes to a pattern of dots painted on the membrane's flip-side are captured by a small camera; electronic processing yields a 3-D representation of the tissue surface on a computer. Thierman says the probe can distinguish between tissue densities, allowing detection of a rigid tumor beneath a layer of fat. Doctors will be able to feel as well as see tumors once Thierman maps the image to a force-feedback device—a project now under way.


You've never been great with numbers
but you are a pretty good farmer. Now, thanks to e-services, you can concentrate on what you do best. Everything else—accounting, payroll, supply chain, you name it—you can outsource over the Internet. E-services allow you to tap into applications on a pay as you go basis. So you can get back to your core competency. And start counting your profits. www.hp.com/e-services
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Brain Implants: A Lousy Idea

I had just finished giving a talk on the Information Revolution when a young man approached me and said: "What I really want is a brain implant so that I can move massive amounts of information rapidly and painlessly in and out of my head." "You mean so that you can download and upload information without going through the slow eyeball, mouth and ear interfaces?" I countered. "Yes. Isn't that a great idea?" he replied, much encouraged by my reaction. "No. It's a lousy idea," I said, "...unless you are talking about sensor or effector chips," and went on to explain.

If you cannot hear because of inner-ear damage, but your auditory nerve is sound, then a cochlear implant may restore your hearing, as it has for thousands of people who underwent the two-hour procedure: A small receiver is placed within the bone behind the ear, with its two dozen electrodes surgically implanted into the cochlea, where they can electrically stimulate the auditory nerve. An external device, worn behind the ear, picks up sounds, converts them to electrical signals, and conveys them through a tiny transmitter to the implant and hence the cochlea. The auditory nerve then carries these stimuli to the brain where they are perceived as sounds. The same principle applies to people with a deficient retina and a healthy optic nerve. But because vision is more complex than hearing, the precursors to retinal implants are only now being tried on a few human beings. Sensory implants like these that help people recover a lost sense are a great idea.

Working in the other direction is also feasible: We can embed a chip in a muscle to detect the electrical signals our brain uses to flex that muscle. We can then transmit this information to a machine that will open a door or steer a wheel-chair, whenever we tighten that muscle. Some people have even been able to do simple on-off tasks like these by altering, somehow, their own brain waves, which are detected noninvasively. Such effector implants and approaches can help people gain or augment motor functions, and are also a great idea.

If sensor and effector implants are so great, why not extend them to the brain, as my young listener craves, and perform even more spectacular feats? Every night, while asleep, you could be downloading into your own human memory entire sections of the *Encyclopedia Britannica.* Or, you could connect your brain chip to mine, so that we could intercommunicate our thoughts, directly and rapidly.

One good reason for not doing these feats is our ignorance. While we are able to channel simple electrical signals into and out of our body for sensor and effector functions, we don't know how to do so for more complex cognitive tasks: Where and how, within your brain, might a surgeon connect a chip's tentacles to communicate a concept like "freedom"? While scientists have been steadily gaining new knowledge about the brain, they are far from knowing how concepts are represented in it and how we might begin tapping them.

But let's be optimistic, and suppose that after a while we do crack this mystery and manage to connect chips to our brains so as to communicate our deepest thoughts. Wouldn't that make brain implants a great idea? No!

Imagine that you and I and a couple of other people are successfully interconnected via brain chips. We might look cool with sockets and plugs adorning our heads. But we wouldn't be able to start or sustain a single thought: Everybody else's thoughts would be distracting us, screaming for attention within our heads. We might then realize that in spite of our knee-jerk craving for rapid intercommunication, some isolation among organisms is essential if they are to form a viable society. In humans, this balance between isolation and intercommunication is maintained by our seeing, hearing, speaking and gesturing activities, whose slow intercommunication speed, compared to thinking, most likely represents the best evolution could do to simultaneously preserve the individual and society.

We may undergo plastic surgery for silly reasons, but anyone who has a brain would think twice before tampering with the body's physical core.

Not yet convinced brain implants are a lousy idea? Let's talk about the threshold people may be willing to cross before violating the sanctity of their body: While some may undergo plastic surgery for casual, even silly, reasons, everyone considering a pacemaker implant or a heart transplant is sure to proceed cautiously—and only if life depends on it. It seems that we may disturb our outer surface for less than life-and-death reasons. Not so when it comes to the heart. But, heart and brain are equally central to our being. So, why would anyone implant a chip into his brain, for less than life-and-death reasons—like downloading information? I don't think anyone would. Not even my young listener, if he were actually facing a neurosurgeon's drill! We have wisely set a high threshold for tampering with the core of our being, because of fear, but also because of natural, moral and spiritual beliefs. Whatever our reasons for respecting the sanctity of our body's innermost core, they spell out, one more time, that...brain implants are a lousy idea! ◊

PHARMACEUTICALS

When Genes Come True

The first batch of drugs derived from genomics is on the way

"WE DID IT!" SHOUTED T-SHIRTS sported by the twenty-something technicians in the hallways of Human Genome Sciences (HGS) at a ribbon-cutting ceremony this spring. The staff at the Rockville, Md., biotech company was celebrating the opening of a $42 million manufacturing plant that marks the firm's evolution from research startup to an aspiring drug maker.

The event is also a watershed in the emerging era of human "genomics"—the large-scale study of man's estimated 80,000 to 100,000 genes. HGS helped kick off the commercialization of the field in 1992, when it was founded with plans to use scores of automated DNA sequencing machines to rapidly decode genes. Now, $275 million later, HGS is taking the first batch of drugs discovered via genomics methods into human testing.

Before genomics, the path to a biotech drug typically began when scientists identified the gene that coded for an important, well-studied protein, such as insulin. With the genetic recipe in hand, they could use recombinant DNA techniques to genetically engineer microbes used in large-scale manufacturing of the protein.

JAMES STEINBERG

But finding a protein's gene often was a painstaking enterprise that took years of effort. So, HGS and other genomics companies decided to reverse the process by decoding human DNA on a massive scale. They then could fish out genes and work forward, biochemically speaking, to discover new proteins that are involved in disease processes.

It's a rapid-fire approach that William Haseltine, HGS' CEO, has long said would produce a new pharmacopeia. Starting last year, the company began making good on the promise, introducing several candidates into early-stage human clinical trials, including proteins for protecting bone-marrow cells in chemotherapy patients and for facilitating wound healing.

The technology is also identifying hormones and enzymes that conventional drugs can target. Genomics is responsible for more than half the therapeutic targets that pharmaceutical giant Bristol-Myers Squibb in Princeton, N.J., now has in its sights, according to director of science and technology Ron Peppin.

A costly, uncertain road lies ahead before any blockbuster with an HGS logo appears on pharmacy shelves, however. Less than one-quarter of drugs pan out in clinical trials, a process that can easily cost more than $100 million and last a decade.

—Ivan Amato

COMMUNICATIONS

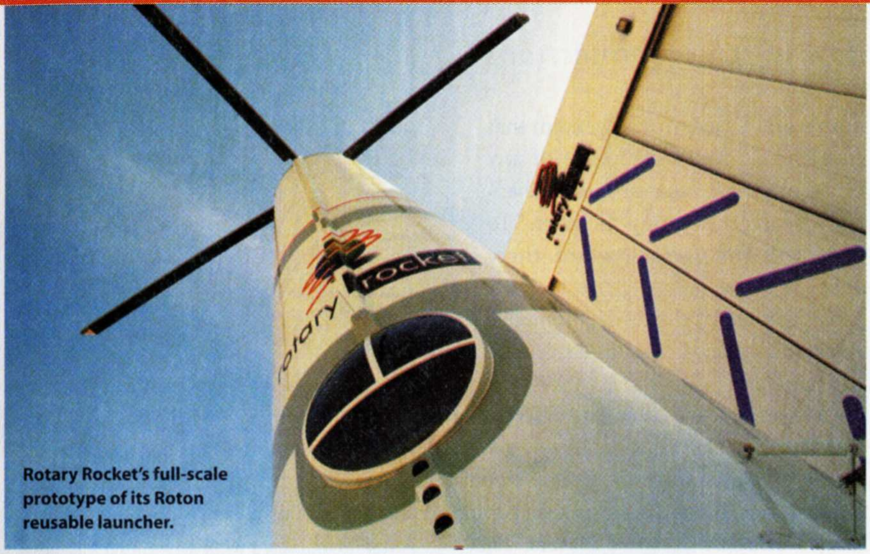
Bandwidth Trading Hits the Big Time

Telecommunications capacity is starting to be treated like pork bellies, as commodities-style bandwidth exchanges gain momentum. Startups such as London's Band-X and New York's Arbinet Communications got the first bandwidth trading market off the ground last year *(see "Bandwidth's New Bargaineers,"* TR *November/December 1998)*. Now the big boys are swooping in.

Energy giant Enron has announced plans for a competing trading system that would allow telecommunications companies and Internet service providers to rapidly buy and sell space on fiber-optic lines. Currently, leasing a high-speed data line can take weeks to negotiate and implement. Enron plans to shave that to seconds with standardized trading contracts and by building a switching facility able to route telecom traffic. Enron will recruit an independent accounting firm to run the bandwidth exchange, which is expected online by year's end. Enron itself, which owns 16,000 kilometers of fiber lines, plans to be a major user.

However, there will be plenty of competition. Arbinet just raised $12 million to expand its trading network. And with other startups expected to announce major venture capital funding soon, the battle to become the bandwidth trading post of choice is likely to grow fierce.

—Katherine Cavanaugh



Rotary Rocket's full-scale prototype of its Roton reusable launcher.

ROTARY ROCKET CO.

AEROSPACE

Reusable Rockets Get Ready

But is anyone prepared to pay for them?

REDUCING THE HIGH COSTS OF PLACING a satellite into orbit has been a major goal for the aerospace industry for years. The current cost of sending up a satellite starts at a couple thousand dollars per kilogram on unmanned, expendable boosters like the Atlas and Delta. Reusable launch vehicles (RLVs), however, could put satellites in orbit for significantly less.

At least one of these promising new rockets is preparing to fly. Roton, which is being built by Redwood City, Calif.-based Rotary Rocket Co., is ready to begin atmospheric test flights. If all goes according to plan, the cone-shaped Roton will take off like an ordinary, single-stage rocket. After delivering its satellite payload in orbit, the vehicle will re-enter the atmosphere, sprouting a set of rotor blades that allow it to land like a helicopter.

The Roton is one of several RLVs that could be in service within two to three years—if companies can raise the money needed to build the vehicles. Indeed, for RLV hopefuls the hardest part may not be developing the technology but obtaining the money needed for construction. Rotary has been one of the more successful companies, but while it has raised $30 million—enough for a full-scale prototype—it will take another $120 million to build the first commercial Roton. Rival Kistler Aerospace has raised more than $400 million for its two-stage RLV, but still needs several hundred million more. Others have generated only a tiny fraction of their needed funding.

If RLVs show such promise, why aren't investors more interested? A major concern is the uncertain size of the market. Most proposed RLVs are best suited for launching small satellites into low orbits (typically less than 1,500 kilometers). Hundreds of these satellites will form the infrastructure of the global telecom systems for companies like Iridium, Globalstar and Teledesic. But with Iridium facing financial problems and with Teledesic's design in flux, demand for RLVs is uncertain. The proposed RLVs are not powerful enough to lift heavy communications satellites 36,000 kilometers up into geosynchronous orbit for broadcasting television and other signals—the faster-growing segment of the business.

Still, developers of RLVs are not daunted. Gary Hudson, CEO of Rotary, notes that RLVs like Roton would be capable of servicing satellites already in orbit and delivering crews to the International Space Station, not just launching satellites.

If RLVs can deliver on their promise of low-cost space access, they may open up markets such as rapid cargo delivery or space tourism. Attempting to predict such a future, says RLV advocate Max Hunter, would be like "explaining Hollywood to Queen Isabella." **—Jeff Foust**

MATERIALS SCIENCE

Raising the Nanotech Flag

Putting together materials and devices atom by atom in order to exploit novel properties is one of the most promising areas of investigation in everything from microelectronics to medicine. But much of the research in this field, called nanotechnology, is scattered throughout more mature disciplines, such as physics and chemistry. Likewise, federal funding is disjointed, with money flowing out of various agencies.

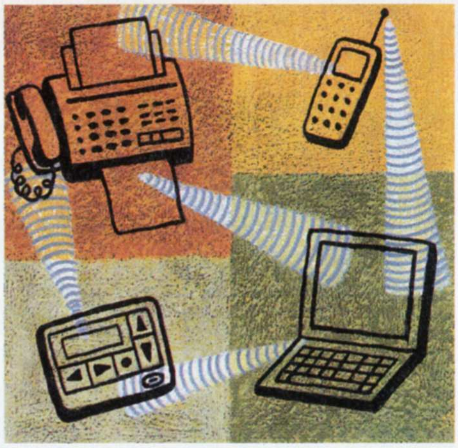
A national nanotech initiative could change all that. The proposal, outlined by a panel of officials from the National Science Foundation (NSF) and other governmental agencies, would double federal spending on nanotech to roughly $500 million annually and would establish a series of multimillion-dollar nanotech research centers. It would also attempt to coordinate spending. President Clinton is expected to decide in September whether to include the initiative in the fiscal 2001 budget.

The increased support is critical to build the infrastructure needed to develop nanotech in the United States, says Mike Roco, a program director at NSF and chair of the Interagency Working Group on Nanoscience, Engineering and Technology that drafted the proposal. The initiative also could boost the image of nanotechnology *(see "Nanotechnology: The Hope and the Hype," TR March/April 1999)*. "This erects a flag that there's a field called nanotech," suggests Richard Smalley, director of Rice University's Nanoscale Science and Technology Center. **—David Rotman**

NETWORKING

E-toys Unite!

Bluetooth will allow wireless connections



JAMES STEINBERG

ALL TOO OFTEN, THE REALITIES OF LIFE tarnish the utopian rhetoric about our interconnected information society. Try checking your e-mail or surfing the Web on your portable PC in a hotel room, and you'll experience the annoying gap in the fabric of the wired world.

Help is on the way. A consortium that includes most of the leading computer and telecommunications companies is devising a standard that will enable all manner of gadgetry to communicate across short distances through radio waves. The initial specification for the "Bluetooth" standard is expected to come out in July, and Bluetooth-enabled products should be on the market in the first half of 2000.

Driving the effort are Bluetooth's founding members Ericsson, IBM, Intel, Nokia and Toshiba. About 650 other companies are now participating in the Bluetooth Special Interest Group, developing the hardware and standards that will make the idea a reality. Members of this consortium work under an arrangement that gives them royalty-free usage of any Bluetooth intellectual property developed by another group member. "To make this a *de facto* standard, there needs to be no licensing fees to companies that use it," explains Simon Ellis, marketing manager for Intel's mobile and handheld products.

Bluetooth (the moniker refers to a 10th-century Danish king) is not a substitute for other forms of wireless communications. It operates over a very short range—roughly up to 10 meters. That's plenty far enough, however, for a slew of applications. Your handheld organizer, for one thing, could radio its contents to the PC in your briefcase, updating its address book and appointment calendar. A Bluetooth-equipped computer on the passenger seat could dial up a Net connection using the cell phone in your pocket, download e-mail—and page you if it retrieved any messages marked "urgent." A Bluetooth headset could even read your messages to you aloud while you drive, using commonly available text-to-speech software. Bluetooth-equipped keyboards, mice, printers and other peripherals would dispense with the need for many of those annoying connection cables.

Bluetooth will operate in a microwave portion of the radio spectrum (between 2.4 and 6 gigahertz) that is now used by some microwave ovens as well as an assortment of industrial, scientific and medical equipment. This is an "unlicensed" swath of spectrum, meaning anyone who wants can use it. To avoid interference problems, Bluetooth will employ a frequency-hopping technology. Devices in proximity with one another establish an ad hoc network in which the transmission frequency changes 1,600 times a second in a programmed sequence, in effect dodging potential interference.

Does the world really need another networking technology? Analysts say yes—if costs are kept low. The goal is for Bluetooth modules to add only $5 to $10 to the cost of a product—a trivial margin for a portable computer or handheld organizer, though a bit more significant for a cell phone or pager. If manufacturers hit that target, Bluetooth could "revolutionize the way people use" information devices, says Phillip Redmond of the Yankee Group in Boston.

Bluetooth is not the only game in town for short-range wireless connections. Infrared links can serve much the same purpose—and are being built into a growing number of computers and peripherals. Unlike Bluetooth, however, infrared communication requires that the devices point at each other. Because of infrared's line-of-sight constraint, some predict, Bluetooth will prevail. **—Herb Brody**

SATELLITES

God's Eye Stays Shut

Space Imaging's ambition to be the first company to offer high-resolution satellite images commercially *(see "God's Eyes for Sale," TR February/March 1999)* suffered a setback in April when the company's IKONOS-1 satellite failed to reach orbit. The Athena II rocket's payload fairing—the nose cone that protects the satellite during launch—failed to separate as planned several minutes after liftoff. The fairing's added mass kept the satellite from gaining enough speed to reach orbit, and the satellite burned up as it re-entered the atmosphere.

SPACE IMAGING

IKONOS-2 could launch as early as July.

Space Imaging has a backup twin satellite, IKONOS-2, which the Thornton, Colo.-based company hopes to launch as early as July. "Although our business plan will be delayed," CEO John Copple says, "we are confident that with the launch of IKONOS-2 we will achieve our goals."

That delay, though, may enable competitors to catch up. Orbimage of Dulles, Va., and EarthWatch of Longmont, Colo., are planning separate launches of high-resolution imaging satellites later this year. All three outfits plan to offer satellite images with resolutions as sharp as one meter, more than twice as crisp as what is commercially available today. **—Jeff Foust**

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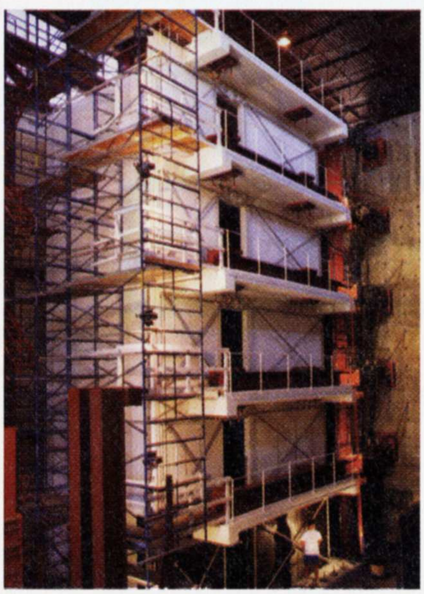
CONSTRUCTION

Concrete Left Standing

Fake earthquakes test safer building methods

THEY'RE NOT GOING TO HUFF AND they're not going to puff, but researchers at the University of California at San Diego (UCSD) are wielding 10 huge hydraulic jacks that could easily bring a shoddily constructed house down. The team is using the jacks to subject a 60-percent-scale model of a five-story concrete building to a series of simulated earthquakes; like the third little pig, they believe they've got a better building technique that will keep their structure standing.

The testing is the culmination of a 10-year collaboration between universities, industry and the National Science Foundation to develop seismically sound structures using prefabricated, or "precast," concrete. Builders generally prefer precast to poured-in-place concrete—it's cheaper and faster to erect. What's more, factory fabrication allows for better quality control and frees a project from the whims of the weather. But conventional precast construction is susceptible to damage from earthquakes, and building codes have traditionally frowned upon its use in earthquake-prone areas such as the West Coast.



UCSD

Earlier trials at UCSD's structural "lab."

That could all be about to change. UCSD Professor of Structural Engineering Nigel Priestley, who coordinates the collaboration, says that the results will form the basis of new design recommendations and ultimately new building codes. Tests will give data on four different systems for connecting columns and beams, two approaches to flooring and one method of connecting wall panels. Researchers will simulate several earthquakes of increasing intensity by pushing on the structure with the hydraulic actuators.

The researchers expect the tests to show that—if the right methods are used—the precast concrete systems actually perform as well as, or better than, those dictated by existing codes.

—Rebecca Zacks

PATENTS

Guerilla Webfare

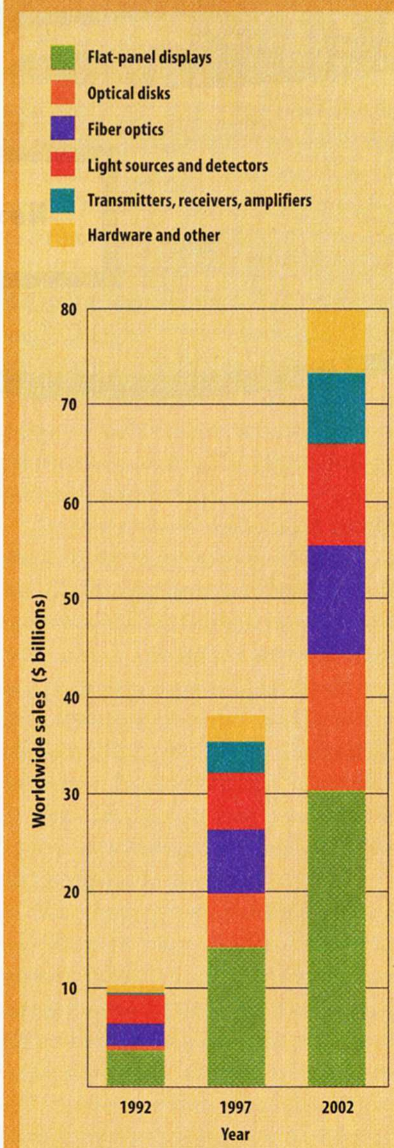
THE NONPROFIT WORLD WIDE WEB CONSORTIUM (W3C) HAS POSTED A PUBLIC PLEA on the Internet for information it needs to overturn a patent held by one of its members, Intermind, that covers methods of exchanging metadata (data about data) over networks. The patent covers parts of the W3C's new protocol for protecting the personal information of Web users, known as P3P. The standards body wants P3P freely adopted; Intermind wants royalties from users.

W3C's officers launched an assault on the patent using a Web page that urges readers to search for and submit prior art—papers, memos, anything that could show Intermind wasn't the first to come up with the metadata scheme. If prior art is found, the patent could be declared invalid. There's precedent for the patent-busting tactic. Last year, Netscape Communications used an Internet appeal to help beat back a lawsuit from Wang Laboratories. "It can only work if you have a willing group of searchers," says Alan Fisch, a litigator with Howrey & Simon in Washington, D.C. "But there is no shortage of people who find software patents counterproductive." **—Antonio Regalado**

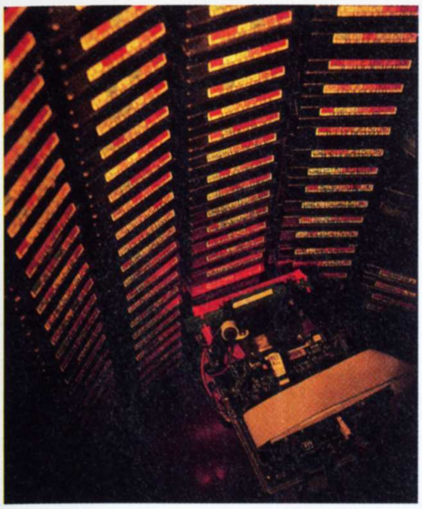
PHOTONICS

Decade of Light

From the lasers that make it to the fibers that carry it—the hardware of light is booming. According to the Optoelectronics Industry Development Association (OIDA), which tracks component sales, growth in flat-panel displays will continue to top all segments as they begin to replace cathode-ray tube monitors on desktops. Sales of light sources, such as lasers and light-emitting diodes, will be driven by increasing use of optical disks for data storage, as well as fast-growing fiber-optic telecommunications networks. By 2002, OIDA predicts, the industry will be selling some 80 million kilometers of optical fiber per year.



SOURCE: OIDA



STORAGE TEK

The Internet Archive is stored on digital tapes.

WEB

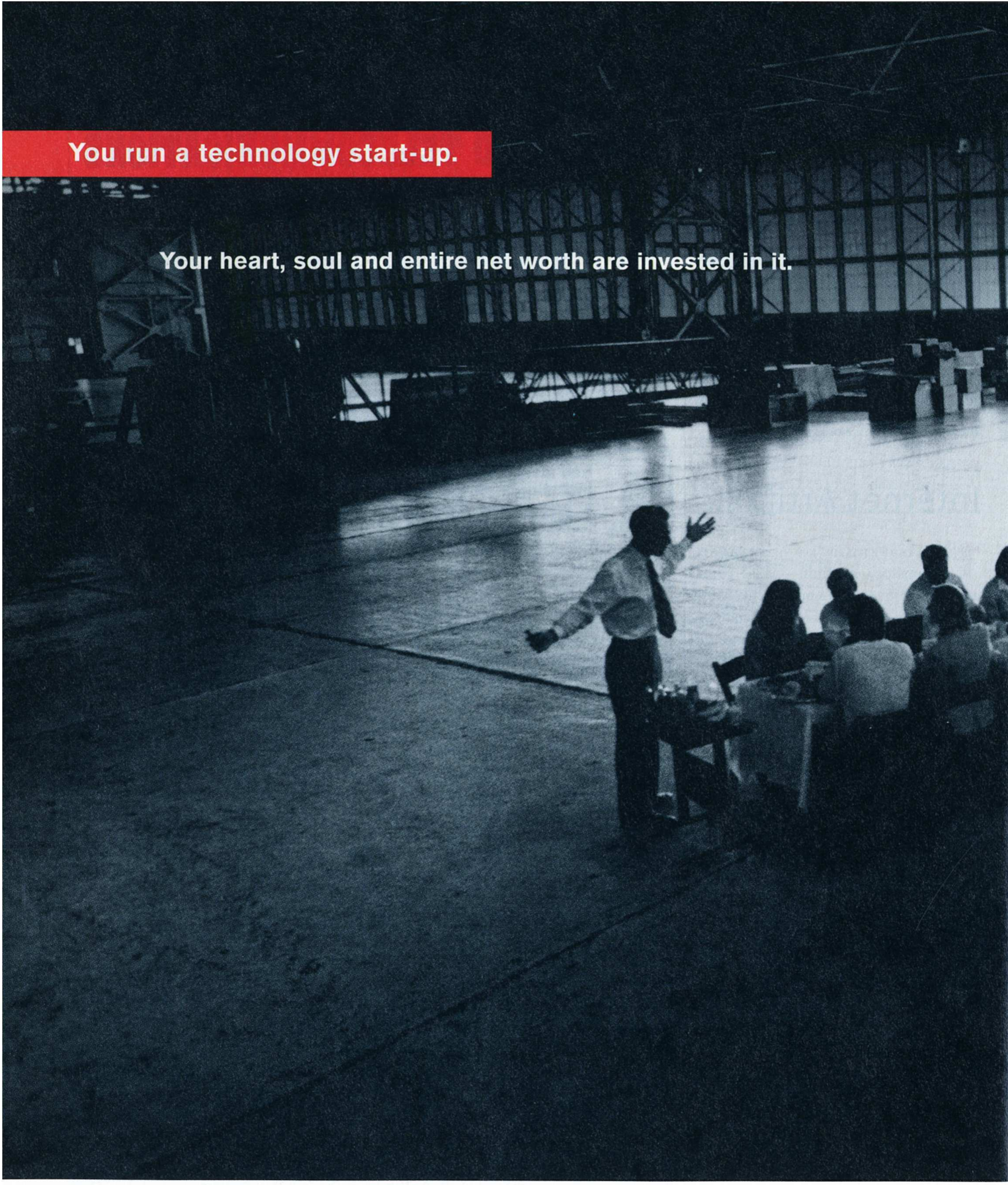
Internet Artifacts

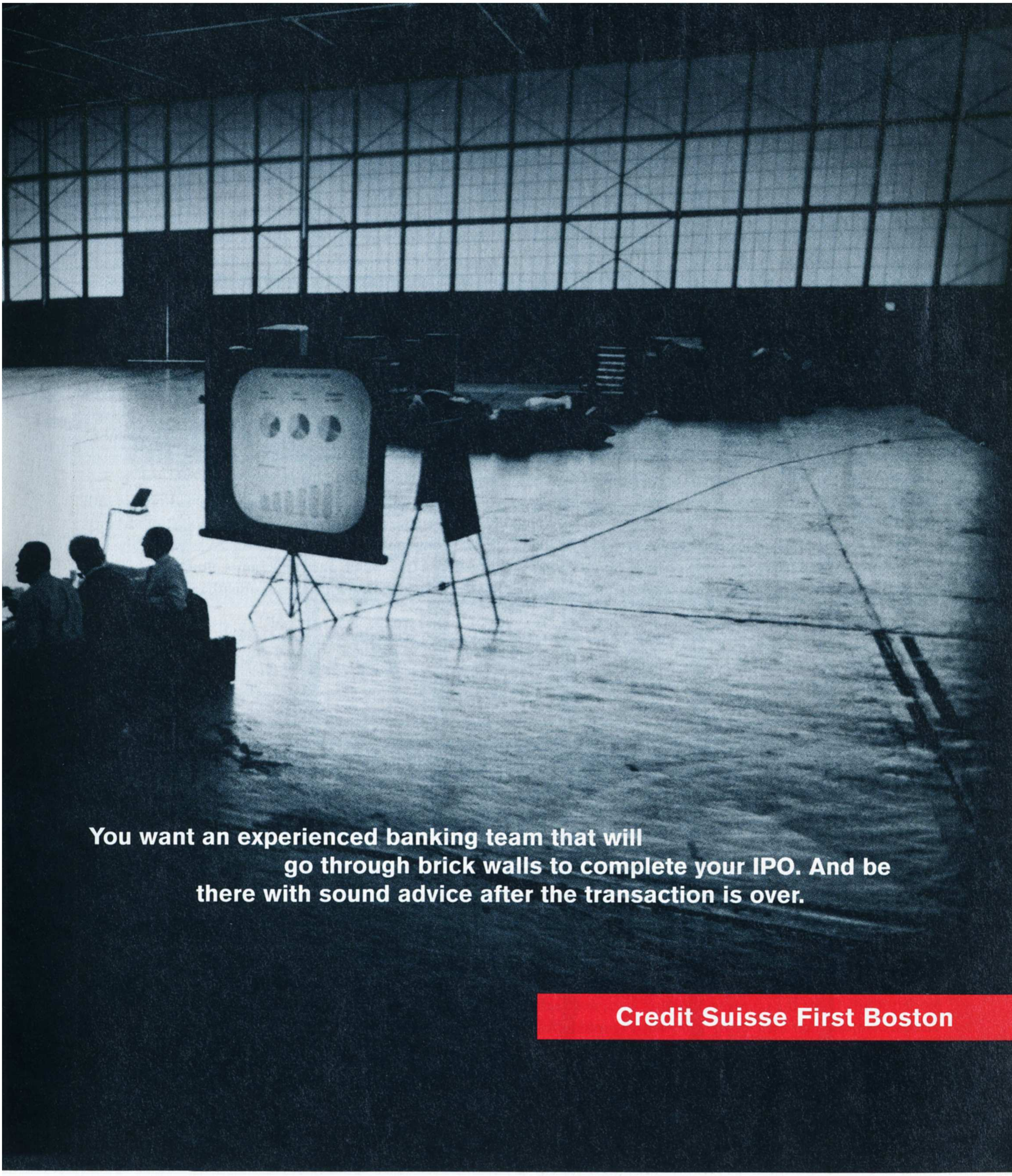
THE INTERNET IS, BY ITS VERY NATURE, a transitory medium—pages come and go. But if you had a publicly available Web page in the past three years, chances are that a copy of it is in the collection of the Internet Archive, a nonprofit group that saves "snapshots" of the Internet.

The Archive was founded by Brewster Kahle, whose San Francisco-based Web browser company, Alexa Internet, collects the snapshots every two months and donates the digital tapes to the Archive. As of May, the Archive was in excess of 13 terabytes (a terabyte is 1 million megabytes); in comparison, the Library of Congress holds the equivalent of about 20 terabytes. The Archive is stored in two separate machines in different locations. "It's too important to have in one place. An earthquake could cause destruction of a collection that's as large as the largest library ever built by humans," says Kahle.

But it is proving easier to save the information than to sort through it for any useful purpose. While recent data are stored on disk for quick retrieval, the bulk of the Archive is in a library of digital tapes that are too slow to search effectively. Currently, the only way the public can get at it is through the Alexa toolbar (downloadable at www.alexa.com), but, at the time *TR* went to press, only about the last six months of snapshots were available. When the reading room for these massive stacks is finally built, however, the Archive will be quite a collection.

—Deborah Kreuze


You run a technology start-up.
Your heart, soul and entire net worth are invested in it.


You want an experienced banking team that will
go through brick walls to complete your IPO. And be
there with sound advice after the transaction is over.
Credit Suisse First Boston

The Real Global Village

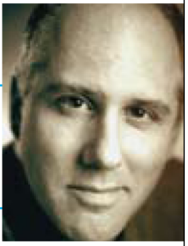
BORNEO—LIGHTNING FLASHES ACROSS THE DENSE forest, and buckets of rain wash away the day's heaviness. Night falls on this Dayak village, perched on a hill above the Kayan River.

Inside the home of the leader of the village, two dozen people sit down on the concrete floor for an evening meal. Once a week, these subsistence farmers gather for food, conversation and a few cups of rice wine. They usually eat by candlelight, because their village lacks electricity. It does not, however, lack innovators.

On this evening, the villagers wish to see their food and the faces of friends. Candles aren't enough. Two men struggle with a bulky battery, attaching two connections to a long, thin fluorescent lamp that hangs from a post in the middle of the room.

The light won't work. One man brings out a hammer and a pliers and taps and tugs at the connections. He reattaches the wires once, twice, then a third time. This last time, the light comes on. The people smile and pounce on their food.

In a Borneo village, electric light is welcomed, but the telephone is viewed with skepticism. Is there a lesson here about how innovation is adopted?



A world away from e-commerce, databases and cell-phones, these villagers grow rice and pepper in much the same way as their ancestors did 400 years ago. Yet they wish to adapt technology to their particular circumstances in much the same spirit as many Americans. Technological innovation, in other words, isn't found only in university labs or corporate design centers, but in the rainforests of Borneo, the bush of northern Australia or the grasslands of southern Africa.

This claim invites skepticism, of course, so let me explain. I am not saying that primitive technologies are the equal of modern ones. Quite the opposite. Peasants want new technologies, but on their own terms. They want to mold these technologies to the patterns of their lives. How they do so offers important lessons about innovation.

This is not an armchair column. I have visited the same Borneo village four times in the past four years, partly to observe how Dayaks—people of the Pacific region who were the first recorded settlers on Borneo—absorb and adapt new technologies.

Consider the arrival of the outboard motor in the villages along the Kayan. Many river villages in Borneo can be reached only by boat. The family I know best here—the Jagaus—bring their children to school by boat. The boats are long and low, made from local wood, usually by the owner himself. Before the motors came, men steered the boats with long poles, relying on the river currents for speed.

In the space of a decade, travel has changed. Outboard motors went from a rarity to a commonplace. Today even the poorest family has at least a small outboard motor to speed the journeys up and down river. The power is seductive. Villagers clearly envy those with more powerful motors.

Still, there are limits. The river is shallow, so that only relatively low horsepower motors are any good. Because of this, traditional boats hold sway. It may be that the farmers can't afford to buy commercially made boats, which could handle higher-powered motors. But it is more likely that the villagers like the boats they have. They have made them with their own hands, or know the person who has, and they are not ready to give up that sense of intimacy.

Their embrace of new technology is partial. So it is with the chain saw, another complicated symbol of modernity. From many angles, the chain saw is a marvelous tool. The task of felling a tree, which once took hours, now takes minutes. In the village, the elder Jagau son, Jonathan, owns a chain saw, and he sells his services to his fellow villagers, who come into cash by selling pepper or gaining remittances from children or relatives who hold jobs in Kuching, the nearest city, three hours away.

It is against Dayak tradition to sell wood from communal land to outsiders, so that Jonathan only cuts trees when people need the wood. He doesn't give them raw logs either. In another case of creative improvisation, he uses his chain saw to carve logs into rough planks of wood. He is literally a one-man sawmill thanks to his German-made chain saw.

This sense of scale informs the villagers' hopes for new technologies. For many years, they have asked the government to bring electricity to their village, and telephone lines too. Jonathan's father, who goes by the single name Jagau, is the village headman. He says that a new road, to be built along the river, should bring with it power and phone lines. Electricity will be welcomed by making lights and television a daily event, but he is less sure of the telephone's value.

Standing in his pepper garden one day recently, Jagau, dressed only in a loincloth, prunes a tree with his machete, then catches a breath. I ask him whether he will have a phone inside his house. He looks at me as if I am crazy. "Who would I call?" he asks. Before I can answer, he says the entire village will only need a single phone.

With a swift thrust of his muscular arm, he points to a place in the center of his village, where he imagines the phone will go. ◊

Biotech Goes Wild

Genetic engineering will be essential to feed the world's billions. But could it unleash a race of "superweeds"? No one seems to know. And nobody's in charge of finding out.

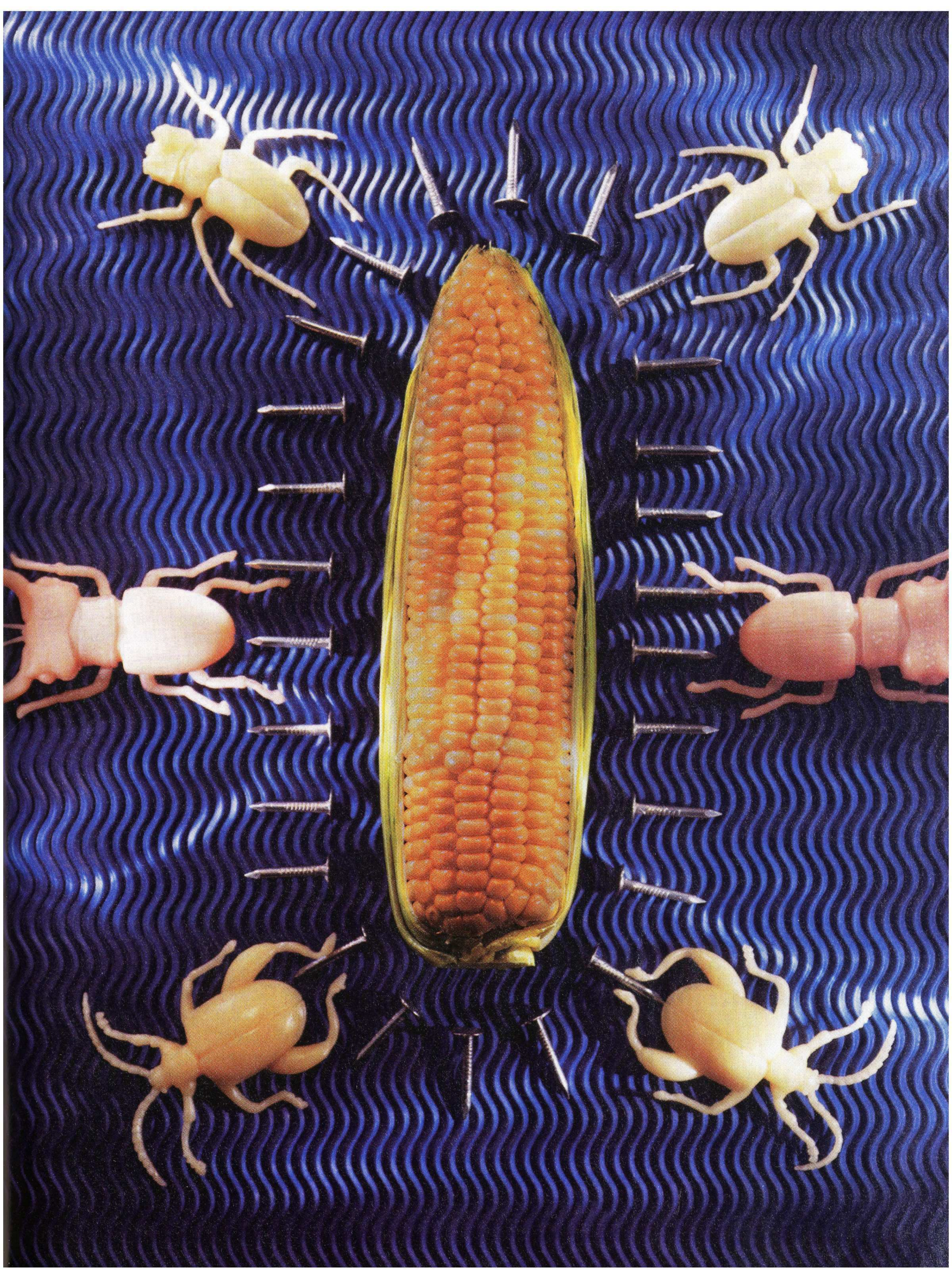
BY CHARLES C. MANN

PHOTOGRAPHS BY VITO ALUIA

A FEW MILES OUTSIDE SACRAmento, several large greenhouses sit behind a fence. In the summer the familiar heads of sunflowers are visible through the glass and in the fields surrounding the greenhouses. The plants are tall, straight and healthy, with thick leaves that reach for the California sunlight. They look exactly like sunflower plants grown throughout the United States—except for the plastic cages around each flower.

The flowers are covered by biologists at Pioneer Hi-Bred's research facility in Woodland, Calif., which owns the greenhouses, the fields around them, and the sunflowers in both. The plants are transgenic—that is, genes from other organisms have been inserted into their chromosomes. Caging the sunflower heads helps prevent the breeze from wafting genetically engineered pollen around the area, which would violate federal laws banning release of unapproved transgenic organisms.

To protect Pioneer's trade secrets, the researchers are chary of discussing their work, but government permits suggest that the sunflowers in Woodland have been subjected to the full armamentarium of contemporary biotechnology. Pumped up by genes from as many as a half a dozen other species, the plants repel moths and viruses, fight off fungus diseases, and produce seed with a shelf life beyond that of their nonengineered cousins. To Pioneer, these super-sunflowers, as they are sometimes called, will be a small but significant step forward in the struggle to feed the world's exploding population, which is projected to level off at 10 billion or so. But to critics, they—and the agricultural biotechnology that created them—are an ecological menace that will wreck the natural systems on which human life depends.



The battle between these entrenched views is fierce. In the last year, farmers and activists ruined five metric tons of transgenic seed in France, trashed fields of genetically altered crops in Germany, and convinced seven European supermarket chains to stop selling store-brand goods containing bioengineered products. This February, a coalition of 70 groups and individuals sued the U.S. Food and Drug Administration to block the use of a dozen transgenic crops as an "imminent" threat to the environment.

Even as the U.S. government promotes agricultural biotechnology, European countries are backing away from what activists call "Frankenfoods." Austria and Luxembourg have banned genetically modified corn; Norway has also outlawed the corn as well as five other biotech crops; France has prohibited all transgenic plants. To push the British government to enact a moratorium, Greenpeace dumped four tons of genetically modified soybeans outside 10 Downing Street in February.

Biotech's supporters, on the other hand, argue that it will create nothing less than a second Green Revolution. In the first, agricultural scientists used conventional breeding techniques to create the high-yielding strains of wheat and rice that have doubled world grain harvests since the 1950s. During that time the number of hungry people fell by three-quarters, according to the U.N. Food and Agricultural Organization, despite a huge population increase. But global population numbers continue to rise, and researchers now must do it all over again. According to a projection released last August by the International Food Policy Research Institute, a think tank in Washington, D.C., world demand for rice, wheat and maize will increase 40 percent by 2020—and the only way to feed those mouths is through biotechnology. If activists succeed in banning transgenic crops, argues Robert L. Evenson, an agricultural economist at Yale University, they will end up "hurting the poor of three continents."

Caught between these extremes is a group of agricultural ecologists and plant geneticists who are trying to understand the implications of the new technology. Although some activists claim genetically altered crops are a direct threat to human health, researchers generally dismiss such fears: There is little evidence that transgenic genes, in and of themselves, are likely to be toxic or promote disease. However, biologists do believe that in some cases foreign genes in crops can pass into other, nonagricultural species, with potentially dangerous effects. "It's inevitable that they will get out," says ecologist Joy Bergelson of the University of Chicago. "That doesn't necessarily mean that there will be negative repercussions. But there could be some. And right now we don't know enough about what they could be and when they could occur."

"The technology is brilliant," says Paul Arriola, a plant geneticist at Elmhurst College, in Elmhurst, Ill. "In many respects, it's a godsend." Nonetheless, Arriola believes biotech is outpacing both the scientific understanding of its risks and the development of a regulatory apparatus to supervise its use. Because, in Arriola's view, "we don't really know what to regulate, or how to do it," the world is in the middle of "a huge, ongoing experiment. We could create a real environmental mess. And that could stop this technology from doing some real good."

Superweeds

THE FIGHT OVER TRANSGENIC FARMING IS ANYTHING BUT ACADEMIC. In 1996, the first year transgenic seed was widely available, farmers planted 1.74 million hectares (4.3 million acres) of the new varieties. This year, according to Clive James, head of the nonprofit International Service for the Acquisition of Agribiotech Applications, as many as 50 million hectares worldwide—an area bigger than Germany—are planted with genetically modified crops. "It's one of the fastest adoptions of technology I've ever seen," James says.

About three-quarters of that land is in the United States, most

The Terminator Tackles Seed Pirates

"I've had some of my Chinese postdocs ask for a few seeds of transgenic soy to take home to their families," says Neal Stewart, a biologist at the University of North Carolina at Greensboro. "I never know what to say."

For years, biotechnology companies have worried about transgenic soy plants slipping out of their control. Farmers who plant bioengineered crops agree not to save their seed for next year's planting, making them customers for next year's batch of genetically engineered seeds. But even in the United States, where intellectual property rules are strong, such arrangements are widely ignored, despite companies' use of "seed police." In China, the biotech firms fear, "seed piracy" could be rampant.

In the spring of 1998, a technical solution emerged: inserting a gene that prevents seeds from germinating, but doesn't otherwise affect the plant. Referred to by anti-biotech activists as "Terminator technology," the technique was developed by a U.S. Department of Agriculture researcher and backed by Delta and Pine Land, a leading seed company now owned by Monsanto.

To companies, the Terminator is the biotech equivalent of copy-protection: a technological means of preventing seed piracy. Moreover, if Terminator genes were packaged with other transgenic traits, they could help ensure that crop-weed hybrids would be sterile—potentially eliminating a difficult problem *(see accompanying story)*.

Critics see it differently. Farmers have been saving seed for millennia. To those concerned for rural welfare, the Terminator seems like a way to slip a noose around the neck of poor farmers. Fearing farmers in developing countries would become dependent on faraway corporations, the Consultative Group for International Agricultural Research, a network of international agricultural laboratories, declared in December that it would oppose introducing seed-sterility genes to developing nations.

Meanwhile, researchers have developed a dozen newer, more sophisticated variants of Terminator technology—dubbed "Terminator II." Astra Zeneca, for one, has developed a version that in theory cannot grow and germinate unless farmers use certain chemicals from the company. Also under development are transgenic plants whose natural defenses against pests can be switched on and off by chemical signals, which would also be purchased from the company. This strategy is intended to conserve the plants' resources by turning the defenses on only when they're needed. But such "junkie plants" are disturbing to some opponents of agritech because their normal functioning depends on synthetic chemicals.

of it planted in bioengineered corn and soybeans. But the technology is growing even faster in Argentina—the area the country devoted to transgenic soybeans tripled between 1997 and 1998. Although exact figures are not available, China, the world's biggest producer of cotton and tobacco, is, according to James, "aggressively increasing" the land planted with genetically altered versions of both crops.

"killer-bee" plants.

Surprisingly little is known about such natural hybridization, explains plant geneticist Norman C. Ellstrand of the University of California at Riverside. Until recently, agricultural scientists focused on protecting farmers; the small amount of hybridization research done in the past primarily

The worry is that biotech crops will spontaneously breed with wild relatives creating "superweeds."

By far the most important bioengineered trait today is herbicide tolerance, which accounts for two-thirds of all transgenic crops. A technology dominated by Monsanto, it lets plants withstand the use of selected weed-killing chemicals, so that farmers can apply them without fear of destroying their crops. Monsanto's "Roundup Ready" soybeans, which resist the company's Roundup herbicide, were introduced in 1996; last year, they covered an estimated 10 million hectares—a third of the U.S. farmland devoted to that crop. Next in importance is insect-resistant corn, including DekalBt corn, modified by Monsanto's recently acquired Dekalb subsidiary to produce a bacterial insecticide, and StarLink corn, produced by AgrEvo, a joint venture of German chemical giants Hoechst and Schering. Principally aimed at fighting off the European corn borer, transgenic corn last year occupied 6.5 million hectares in the United States—a fifth of the nation's total corn crop.

More—much more—is on the way. As sales of bioengineered seeds rose from $75 million in 1995 to more than $1.5 billion last year, half a dozen huge companies in Europe and the United States positioned themselves to exploit a market that is widely believed to be on the verge of exploding. According to U.S. Department of Agriculture records, some 4,500 genetically altered plant varieties have been tested in this country, more than 1,000 in the last year alone. About 50 have already been approved for unlimited release, including 13 varieties of corn, 11 tomatoes, four soybeans, two squashes, and even a type of radicchio. Hundreds more are in the pipeline, among them plants that will produce industrial and pharmaceutical chemicals *(see "The Next Biotech Harvest,"* TR *September/October 1998).*

This rush to market alarms some biologists, who believe transgenic crops are being released before the environmental implications are understood. The most immediate worry is whether genetically engineered crops will spontaneously breed with their wild relatives, creating hybrid "superweeds." Just as a single Brazilian bee researcher created a continent-wide nuisance by accidentally letting aggressive African bees hybridize with gentle domestic bees, the release of alien genes could, in theory, produce noxious

concerned the introgression of genes from the wild into cultivated species, rather than the other way around. "People had the idea that [crop-weed hybridization] wasn't a very common or interesting phenomenon," Ellstrand says. "But when they finally got around to looking at it, they basically spent a lot of time being surprised at what could happen."

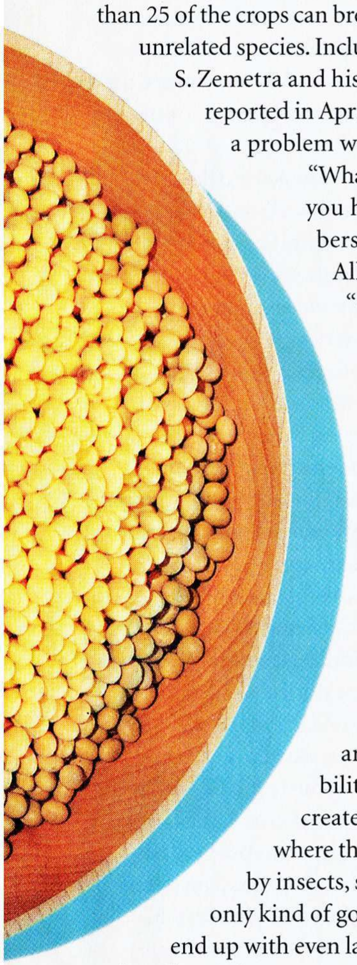
Initially, scientists thought genes were unlikely to flow from transgenic crops to weeds, because known crop-weed hybrids are often sterile. But last September, Bergelson and two Chicago colleagues startled researchers with a study of *Arabidopsis thaliana,* a mustard species often used as a test organism by plant geneticists. Usually, the plant pollinates itself, implying to scientists that foreign genes in transgenic *A. thaliana* would not escape by hybridization. But after the researchers planted ordinary *A. thaliana,* transgenic herbicide-resistant *A. thaliana,* and a naturally occurring, herbicide-resistant mutant variety, they learned that the transgenic plants were 20 times more likely to outcross than the mutants—they were "promiscuous," as a headline in the journal *Nature* put it. "Nobody knows why," Bergelson says. "We're still trying to find the mechanism that drives the pattern we saw. There's a lot we don't understand, including how common it is."

The implications are ominous. A decade ago, for instance, European sugar beets spontaneously mixed with a wild relative, creating a hybrid species that is now a continent-wide problem. Whereas the sugar beet is biannual—the root is harvested at the end of the second year—the new weed is an annual. At the end of the year, Ellstrand says, "the root turns into a chunk of wood that damages farm equipment or gets into the sugar-beet processing plant and screws up the machinery. You can't kill it with an herbicide because any herbicide that gets the weed hits its relative. It's not until the thing blooms and flowers that you see it, and by that time it has set seed that gets into the beet field forever."

Transgenic crops have already shown the potential to create similar problems. The prospect of herbicide- or insect-resistant superweeds is particularly dismaying. In 1995, Monsanto and AgrEvo introduced herbicide-tolerant oilseed rape *(Brassica napus),* the

plant that is the source of canola oil. One year later, an 11-member team from the Scottish Crop Research Institute reported, to scientists' surprise, that pollen from oilseed rape fields can travel as much as two kilometers. At almost the same time, three Danish geneticists discovered that transgenic *Brassica napus* readily breeds with a weedy relative, *Brassica campestris.* The resulting plants look much like *B. campestris*—but are unaffected by herbicides. Taken together, says Dean Chamberlain of the University of North Carolina at Greensboro, the two reports "showed that hybridization is a real concern and that you need a very large buffer area around your plot to control it."

When Ellstrand reviewed the literature on the 30 most agriculturally important plant species, most scientists he consulted believed few hybridize easily. In fact, he found evidence that more than 25 of the crops can break the species barrier, sometimes with unrelated species. Included in that list is wheat, which Robert S. Zemetra and his colleagues at the University of Idaho reported in April can outcross with bearded goatgrass, a problem weed in the western United States.



"What really shocks me as a biologist is that you have two species with different numbers of chromosomes hybridizing," says Allison Snow, a botanist at Ohio State. "Goatgrass has 28 chromosomes and wheat has 42, but they can cross." Biologists have regarded viable offspring from such mismatches as almost impossible. As a result, they thought the range of species that could hybridize was limited. The goatgrass-wheat hybridization suggests that the range is bigger than had been thought.

"You get very low rates of reproduction," Snow says. "But when you're talking about acres and acres of wheat with goatgrass all around them, even a very low probability event can occur." If hybridization created insect-resistant goatgrass in areas where the weed's spread is naturally controlled by insects, she says, "that could end up being the only kind of goatgrass you have, and then you might end up with even larger infestations of it than we already have." Such fears are one reason that insect-resistant Bt crops—which contain genes from the bacterium *Bacillus thuringiensis*—have been targeted by activists.

In the United States, transgenic corn is unlikely to pose much risk of hybridization because it has no close relatives. But Mexico has *teocinte,* the wild plant that may be the ancestor of modern corn. What would happen if Mexican farmers planted bioengineered corn? Could the new genes affect the fitness of *teocinte,* which some agricultural ecologists view as a potential storehouse of valuable genes for future corn breeders? "With the information we have now," Snow says, "it's hard to tell when the long-term risks are serious enough to ban certain crops."

Looming behind the ecologists' fears is the belief that molecular biologists who work with DNA on the laboratory bench don't understand fully how it behaves in the field. According to Rosemary S. Hails of the British National Environmental Research Council's Institute of Virology and Environmental Microbiology, "The risk assessment of transgenic organisms is a multidisciplinary subject, which should include ecologists, molecular biologists, agronomists and sociologists." Instead, companies tend to delegate decisions about the release of transgenic crops to molecular biologists—who are not trained to appreciate the full complexity of how the genetic code interacts with environmental factors.

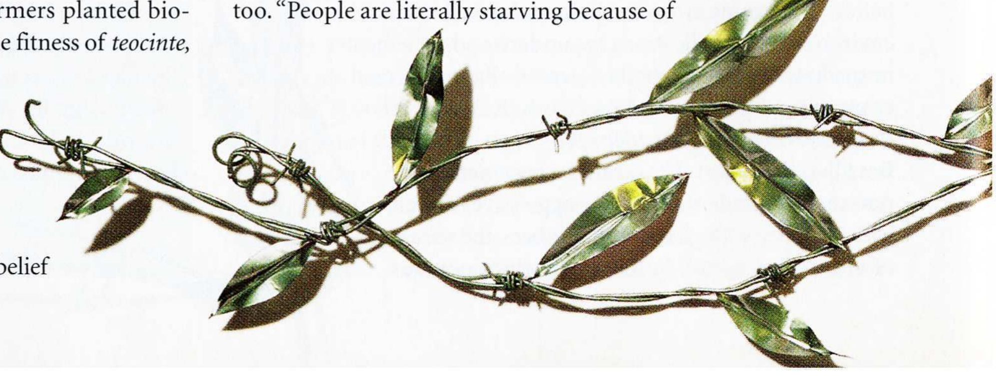
"How fast would a new weed get around?" Snow asks. "Nobody really knows. I'm sort of assuming that most of these crops will be approved eventually and people like me will study what the consequences are. Then, after the cat is out of the bag, we may figure out how to regulate this technology."

A Hungry World

GIVEN THESE RISKS, WHY DO SO MANY OF THESE SCIENTISTS SUPport the continued development of agricultural biotechnology? One answer is witchweed. Witchweed, the common name for three species in the genus *Striga,* is a parasitic plant that feeds on the roots of cereals and legumes in much of Africa. Attacking maize, sorghum and millet—the continent's three most important cereal crops—*Striga,* in the view of Gebisa Ejeta, an agronomist at Purdue University, is a "scourge" of African agriculture. It has been estimated that the weed destroys 40 percent of the continent's total cereals harvest—a staggering loss in the world's hungriest places.

From a biological perspective, *Striga* is fascinating. Its seeds, smaller than grains of sand, lie dormant for as long as 20 years, waking only when aroused by a chemical emitted by the roots of the host plant. While still underground, the parasite plants develop root-like organs called haustoriums, which penetrate the host roots and siphon nutrients. Scores or hundreds of *Striga* plants can attack the same host. Witchweed eventually grows into fields of five-foot-tall plants with pretty pink flowers, but by that time it has long destroyed the crops it feeds on. Because each plant produces as much as 100,000 seeds, witchweed is almost impossible to eradicate—the United States spent four decades wiping out a single small outbreak in the Carolinas.

Because witchweed rapidly adapts to new hosts, losses in Africa keep growing. When the parasite made it impossible to grow sorghum in eastern Sudan, desperate farmers tried to grow pearl millet. At first millet was immune. But within a few years witchweed was wreaking havoc on the new crop, too. "People are literally starving because of



Striga," says Ejeta.

Ejeta and several other Purdue scientists have spent years trying to breed varieties of sorghum that produce low levels of the chemicals needed to germinate *Striga.* But parasite-infested cropland has such dense concentrations of fallow seeds that even the improved varieties can be "overwhelmed," according to Fred Kanampiu, an agricultural researcher in Kenya for the International Maize and Wheat Improvement Center, a Mexico-based laboratory that is usually known by its Spanish acronym of CIMMYT. "The solution is obvious," Kanampiu says. "Herbicides kill witchweed. But unless we can engineer herbicide-resistant sorghum, the herbicides also kill the crop."

Another "obvious" example of the need for biotech in poor countries is broomrape, according to Jonathan Gressel of the Weizmann Institute's Department of Plant Genetics in Israel. The common name for several parasitic species in the genus *Orobanche,* broomrape—the name, Gressel says, comes from its effects on a legume called broom—plagues vegetables, sunflowers and grain legumes throughout the Middle East. Like its cousin *Striga, Orobanche* produces tens of thousands of tiny seeds that lie dormant, ruining all attempts at planting the land. "The seeds are the size of talcum powder, maybe 50 cells per seed," Gressel says. "How they can live for 20 years is beyond me." Methyl bromide, the only available treatment, is expensive, not terribly effective and toxic. "The activists want to ban biotech and herbicides and have farmers pull out the weeds by hand," he says.

Economic models show global malnutrition will increase if biotech is stopped.

According to economists, witchweed and broomrape epitomize the most important potential targets of agricultural biotechnology: the problems of farmers in developing nations. "At first blush you look at this technology and you say this is the last thing that's appropriate for poor farmers," says James of the International Service for the Acquisition of Agribiotech Applications. "It's proprietary, so farmers have to buy seed they now get for free, it's developed by industrial countries, so money flows from the poor to the rich—it must all be ill-suited for developing countries. But when you look at it carefully, the specs of the technology allow you to fit almost exactly what the small farmer needs."

The original Green Revolution crops depended heavily on irrigation, artificial fertilizer and chemical pesticides. By contrast, James says, the fruits of bioengineering are encapsulated in "the simplest technology of all—the seed." Pest-resistant seed corn, for example, needs no costly spraying equipment, is not very complicated to grow, and releases little toxin into the environment. Because poor countries often owe their poverty to bad soils or lack of agricultural water, James believes they will disproportionately benefit from bioengineered crops that can grow in barren land or stand up to drought.

"People in developed countries spend a relatively small part of their budgets on food," says Evenson, the Yale economist. As a result, he argues, productivity increases from transgenic crops will not mean much to Europe or the United States. "We can afford to throw away the technology—it's a luxury for people who already have enough to eat." The situation is different for the destitute. "In some places," Evenson says, "you can get food being more than 75 percent of people's budgets. In rice-based areas, you'd have half of that being on rice. So if rice prices are 20 percent higher than they would otherwise be, it's not a small thing." Last October, he presented a model that, among other things, projected an increase in global malnutrition from stopping biotechnology for 10 years. The exact tally of the starving, he says, "depends on the assumptions, but they are never something to ignore."

"What really bothers me is the increasing opposition, especially in Europe, to using biotechnology for agriculture," says Per Pinstrup-Anderson, director-general of the International Food Policy Research Institute. Although some activists believe that the potential side effects make transgenic research unethical, Pinstrup-Anderson

argues that the ethical considerations cut both ways. "It's probably more unethical to withhold solutions to food problems that cause children to die," he says. "I don't want to be melodramatic but there are several hundred million hungry people in this world."

"Biotech will be a contributor in the future to increasing yields enough to make the world's food supply keep up with population growth," says Stephen Padgett, a chief agricultural researcher at Monsanto. "It won't do the job alone, but it's a crucial part of the effort." Even in the best of circumstances, though, making Padgett's predictions come true will not be easy.

India, for example, initially embraced the new techniques. With the active support of the state, half a dozen Western firms set up collaborative research projects with Indian institutions. In the most well-known of these efforts, Mahyco, the nation's biggest seed company, joined forces with Monsanto to develop insect-resistant cotton—India is one of the world's leading cotton producers. High-intensity cotton farming is notoriously risky to the environment; in India, according to C.S. Prakash of the Tuskegee Institute's Center for Plant Biotechnology, the crop covers just 5 percent of the agricultural land but accounts for 50 percent of the country's insecticide use.

Yet the initial tests in India of cotton bioengineered to resist bollworm caused violent controversy. As a rule, farmers license, rather than own, the seeds for transgenic crops. For this reason, they are not allowed to save the seed from one year's harvest to plant in their fields the next year. Critics both inside and outside India argue that this removes one of the foundations of rural agriculture, forcing smallholders into colonial dependence on rapacious multinationals. The companies respond that the increased yield and decreased costs from biotech will more than make up for the price of the seed each year.

In some instances, however, the big companies think the benefits don't outweigh the costs. In the early 1990s, Pioneer Hi-Bred—then the world's biggest seed company, now a subsidiary of DuPont—developed exactly the kind of transgenic, herbicide-resistant sorghum that could fight off attacks of *Striga*. Then Arriola, the Elmhurst geneticist, demonstrated in 1996 that sorghum easily hybridizes with Johnson grass, a weedy relative that has become an ecological pest in the United States since its accidental introduction from Africa in the mid-1800s. The hybrids, fertile and vigorous, looked very much like Johnson grass.

Because herbicides are almost the only successful means of eradicating Johnson grass, an herbicide-resistant strain would have a major selective advantage. "It would spread," Arriola says flatly. "It could create huge losses." The findings, he says, surprised the molecular biologists; fearful of inflicting ecological damage in North America, Pioneer soon stopped working on transgenic sorghum—postponing the day, perhaps, when Africa can feed itself.

"We're talking about long-term ecological problems," Arriola says. "But how do you look somebody in the eye and say we are not going to develop this crop and feed these people today because we might create some long-term problems in the future? Maybe transgenic sorghum is so risky that everyone knows it just isn't worth it. But how do we make that decision in other cases?"

Who's Watching the Greenhouse?

THE UNCERTAINTY IS DUE, IN PART, TO THE LACK OF a rigorous regulatory framework to sort out the risks inherent in agricultural biotech. The plastic cages covering the heads of the sunflowers help keep the transgenic pollen out of the environment, a general requirement for obtaining a federal permit to grow a test crop of bioengineered plants. But other than monitoring the plots, the government imposes few conditions on biotech tests. The main reason is that Congress has not passed any specific environmental law for genetically engineered agriculture. Instead, transgenic crops are evaluated by three overlapping federal agencies: the Food and Drug

Administration, the Environmental Protection Agency, and the Department of Agriculture.

Each government agency has a different statutory responsibility, which sometimes leads to anomalies—and gaps in regulations. The FDA, for example, doesn't look at the safety of foods that have been engineered to express pesticides, because pesticides are by law exempt from the agency's purview. Nor does the EPA, which is required to treat such foods as pesticides. Because pesticides, of course, are toxic substances, the agency only establishes human "tolerances" for each compound. (Responding to critics' concerns, the agency announced this spring that it may rethink its approach.) For its part, the USDA simply tries to make sure that the crop grows in the way that the manufacturer says it will. The disjointed legal mandates, observes EPA biotechnology adviser Elizabeth Milewski, "make life interesting."

One worrying consequence of this patchwork of regulations is that no one has direct responsibility for looking at long-term effects on the environment. "We have a first-approximation understanding of the population biology of these plants and the insects, microbes and virus populations," says Neal Stewart, a biologist at the University of North Carolina at Greensboro. "But we know very little about the community ecology and virtually nothing about the ecosystem ecology of what these genes will do. And we are not pursuing this knowledge actively." Stewart's concerns bore fruit in May, when Cornell scientists reported that pollen from Bt corn can kill the caterpillars of monarch butterflies.

According to Sally McCammon, science adviser to the USDA Animal and Plant Health Inspection Service, biotech field trials can be of any size and last for any length of time, though one or two years is the standard. From the companies' point of view, the tests are efforts to learn whether new crop varieties will perform as intended. The government's main job, McCammon says, "is to certify that the test is biologically contained." Transgenic plants must be kept apart from plants they might cross-pollinate. "Afterwards you have to account for it," McCammon says. "We make sure that you bag what you take out and that the plant material is plowed under."

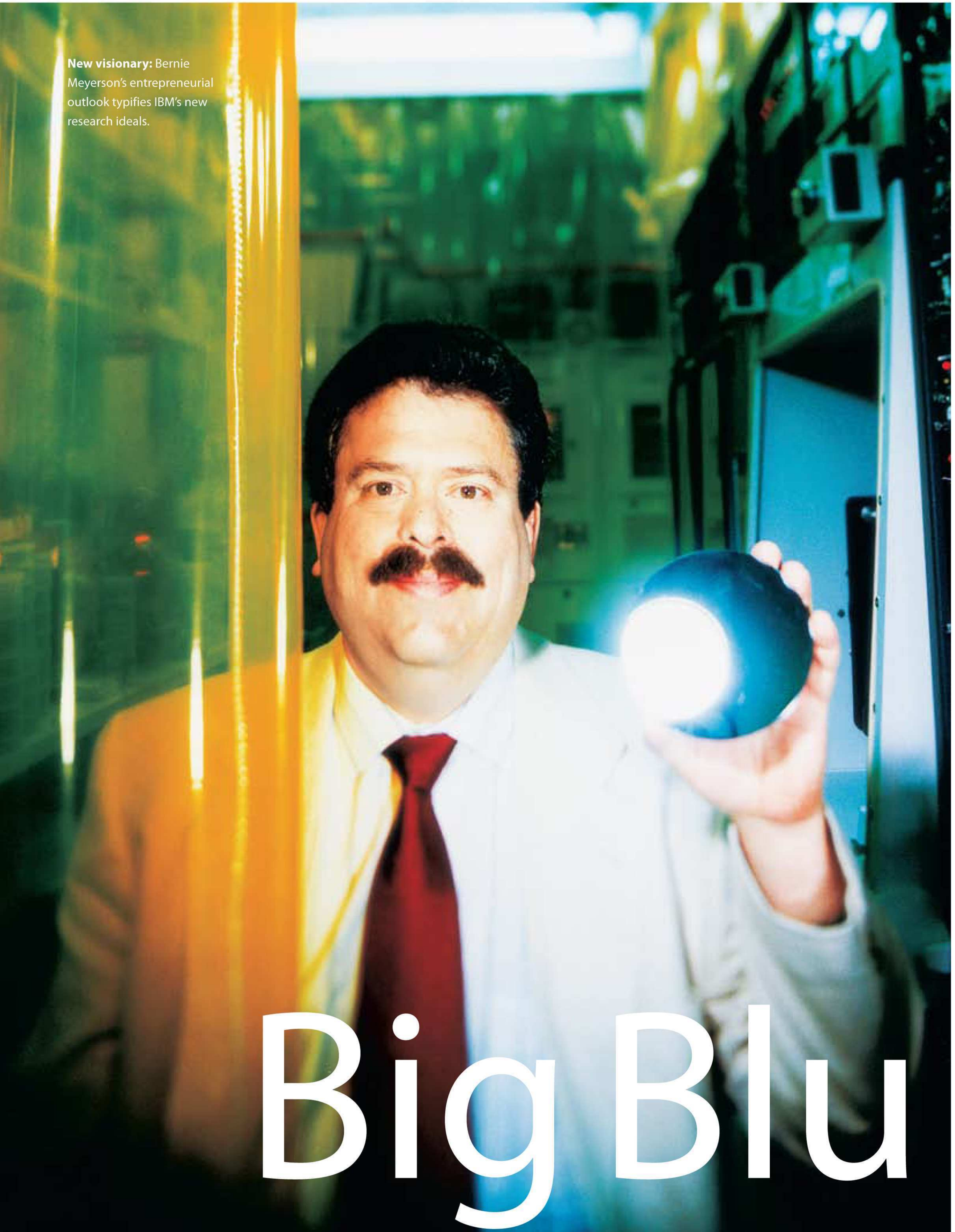
These measures are necessary, to Snow's way of thinking. But by ensuring that transgenic genes won't escape into the environment, they also make it impossible to learn what will happen if they do. "The ecological questions don't even get touched," she says. "In fact, it's illegal to touch them." She believes that the environment and industry would be better served by introducing a second level of testing devoted to ecological questions. Another step, in her view, would be to fund academic research into the ecological hazards—currently the sole source of federal funds, the biotechnology-risks panel of the USDA, has a budget of less than $2 million.

Technical controls may also be possible, says Gressel of the Weizmann Institute. Most transgenic crops today have a single foreign gene. But companies are already working on inserting several genes simultaneously into the plant's genome. In a May article in the journal *Trends in Biotechnology,* Gressel argues that if these multiple genes were inserted in close proximity to each other on the chromosome, potential hybrids would inherit all of them at once. And if the secondary genes coded for traits such as preventing dormancy, the hybrids would be less, not more, dangerous than their wild parents. For crops, the inability to lie dormant doesn't matter, because the seed is harvested and replanted each year. But a weed that is unable to produce seed that can remain dormant until an opportune time to germinate is at a significant disadvantage. "The hybrid weed will be weaker, not stronger," Gressel says.

"I'm more worried about the future than the present," Ellstrand says. "So far it's okay—we don't have killer tomatoes flying through the air. But we need to be thoughtful and careful about what we're doing, and there are some people and some portions of the industry where they have a better tradition of that than others. People who have worked with plants outside in real life seem to have a better handle on it than people who have worked with chemicals all their life. If we keep paying attention to what's happening in the field, we might be able to make this technology realize its promise." TR

Dear Friend,

Heard your Communications network was not feeling up to the new millennium, so we thought we'd send you a Get Well card.



New visionary: Bernie Meyerson's entrepreneurial outlook typifies IBM's new research ideals.

Into the Big Blue Yonder

A few years ago, IBM's vaunted Research division went through a stormy upheaval. But the labs have bounced back, and the future looks bright.

BY ROBERT BUDERI

PHOTOGRAPHS BY SILVIA OTTE

YOU HEAR BERNIE MEYERSON BEFORE YOU SEE HIM—a stream of words fired from behind his office door. Then the man steps forth: bushy mustache, curly hair, sharp eyes, a human whirlwind.

If there's a poster child for IBM Research these days, it's Meyerson. Bristling with energy and drive, he makes things happen—embodying the changes that are bringing the organization, once a hallowed name in R&D, back from its near-death experience of the early 1990s. When IBM officially dropped a long-unfruitful line of semiconductor research, he conspired with a few key managers and colleagues to go underground, borrowing equipment and calling in chits to keep his project alive. Today, the novel silicon-germanium technology his team invented is delivering processors for cell phones and communications networks with lower power and double the speed of conventional rivals—leaving competitors eating IBM's dust.

Befitting his new image, Meyerson occasionally sheds his lab vestments and dons a suit—he has two now—to hobnob with the establishment. He carries a new title, director of telecom technology, and oversees more than 100 people spread across research, design, development and production. He knows the semiconductor business, negotiates deals—and he's in heaven. Meyerson's answering machine holds myriad job offers. But he's not budging. "I could have my own corporate jet and a huge staff and all that other nonsense," he relates. "But it's not what it's about." Instead, he's taking an idea from nothing into a business IBM expects to hit $1 billion in sales in 2001. "Things like that," Meyerson smiles, "you kind of live for."

His employers agree. IBM is hoping new incentives and a fresh outlook that takes researchers into the field to meet customers will encourage more people with Meyerson's entrepreneurial drive. It seems to be working. After a mid-1990s upheaval that saw the division knock some $120 million off its roughly $550 million annual payroll and scale back basic science, Research is turning around. The division has eclipsed its old budget, soared back to near its all-time high in personnel, with some 3,000 employees, and opened labs in Austin, Beijing and Delhi, making eight in all *(see "The World's Largest Industrial Research Organization," p. 50)*. Led by Research, IBM in 1998 won the most U.S. patents for the sixth year running.

What's more, the rise of the Internet and the fusion of communications and computers play perfectly into decades of research—raw computing power, storage, chips, displays, speech recognition, "data mining" and electronic security—that few companies, if any, can match. Managers admit to some holes in their technological arsenal and struggle to woo talent, especially in the face of high-flying Internet startups. Still, the future seems bright and chairman Lou Gerstner showcases Research as central to IBM's revitalization, which helped lift the stock market to record heights this spring. "It's the best time to be in IBM Research perhaps in our history," proclaims research director Paul Horn. "We had great thoughts, we had great things. But we never had the IBM Corporation maniacally focused on how they could get our stuff coming out there to the marketplace faster."

It was not enough for Research to be famous for science and technology. The division had to learn to look out for Big Blue's bottom line.

To Hell and Back

IBM OPENED ITS FIRST FULL-blown research lab in 1945 as an act of vengeance. The company had teamed with Harvard graduate student Howard Aiken to fashion the pioneering Mark I computer, then the world's largest electromechanical brain. But Aiken's press release ignored IBM's contributions, infuriating company patriarch Thomas Watson. Out to construct a superior machine, the "Old Man" renovated a frat house near Columbia University, and launched the lab.

From that seed sprang today's international research organization—the world's largest. Over the next half-century, a flood of technological and scientific triumphs—including back-to-back Nobel Prizes in the 1980s for the scanning tunneling microscope and high-temperature superconductivity—placed IBM at the forefront of industrial research. But while some advances poured billions into corporate coffers, the company failed to turn other Research creations into big profits. Achievements in relational databases and Reduced Instruction Set Computing (RISC), for example, languished for years in IBM's pipeline—only to be snapped up and commercialized by competitors such as Oracle, Hewlett-Packard and Sun. Such failures earned Research the reputation of a "country club," whose members cared little about bringing their ideas to market.

It's hardly fair to place the blame solely on Research. For one thing, IBM's historic success with entrenched technologies sometimes made it difficult for the business groups to accept radical approaches such as RISC. And many of Research's inventions—the first magnetic hard disk drive, for one—did get commercialized by Big Blue. Still, the division's longtime motto was: "famous for its science and technology and vital to IBM." In reality, notes Wolf-Ekkehard Blanz, once a physicist at IBM's Almaden Research Center in San Jose, Calif., and now a manager in Siemens' medical division, "it was perfectly OK to excel in one" of those two goals.

Things reached a head in the early 1990s, when IBM started hemorrhaging money. In spring 1992, research director James McGroddy focused the division more on the bottom line, establishing a new strategy area—Services, Applications and Solutions—whose members worked directly with customers on specific needs. Foreseeing a management change and worried Research might be considered an ivory tower, he also prepared a report detailing its contributions. McGroddy was ready on April 1, 1993, when new boss Gerstner asked senior executives for a description of their operations. Research was first to complete the assignment—and the Thomas J. Watson Research Center in Westchester County, N.Y., was Gerstner's initial company stop outside headquarters. After a five-hour tour, the new boss told McGroddy he had served on the AT&T board and watched Bell Labs struggle to help its parent: "I want to thank you for not putting that problem on my plate here."

Over the next two years, to whip his division into fighting shape, McGroddy reduced his budget 22 percent by cutting overhead and axing redundant or dead-end programs—simultaneously helping Gerstner slash nearly $2 billion from IBM's $5.1 billion annual R&D budget. It was a painful period. Morale plummeted, many good people left. But the real battle had been won that first day. At McGroddy's retirement dinner in late 1996, Gerstner confessed he'd considered breaking up the division—farming its pieces out to business groups—until McGroddy's great first impression convinced him to stay the course.

Research Reborn

SITTING IN HIS EXPANSIVE OFFICE, casually clad in a black mock turtleneck that accentuates the gray in his salt-and-pepper beard, research director Paul Horn is looking happy to have been saved.

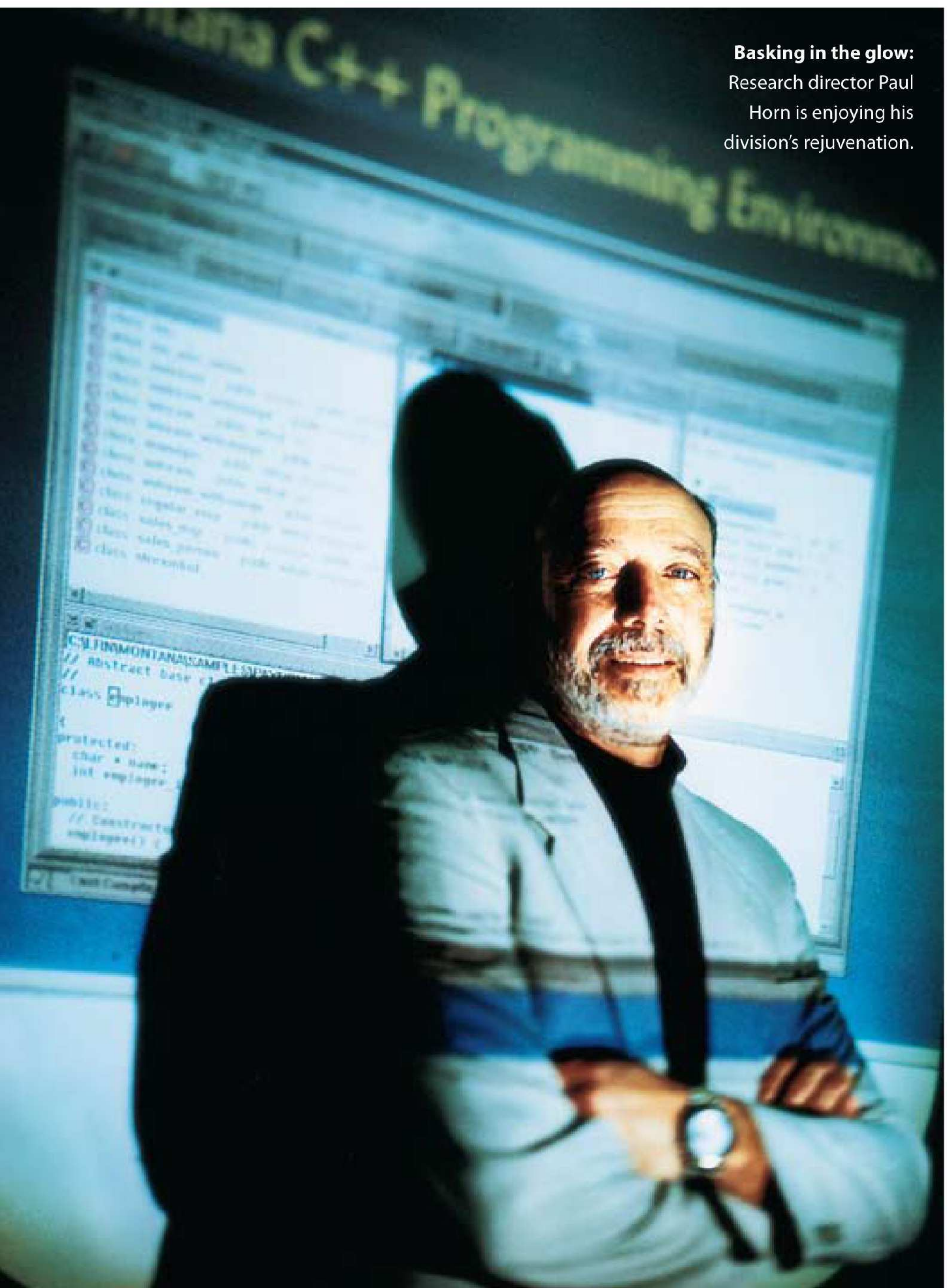
And why not? His division is delivering big time on Gerstner's faith, establishing itself alongside a similarly rejuvenated Bell Labs as one of the world's premier industrial research organizations. After 25 years of hard labor, the Watson lab's trailblazing speech recognition efforts are taking off commercially. Two semiconductor projects are also paying dividends. One is Bernie Meyerson's. The other, announced in September 1997, involves replacing the aluminum used in microprocessors with copper, a superior conductor that makes for smaller and faster chips.

Last fall Almaden lab researchers, whose earlier advances in magnetoresistive data-recording technology *(see "The Big, Bad Bit Stuffers of IBM,"* TR *July/August 1998)* enabled IBM to capture 40 percent of the laptop storage market, announced their Microdrive, a one-inch-square storage device bound for digital cameras and handheld computers. Then there's Deep Blue. Even beyond the free publicity associated with demoralizing chess champion Garry Kasparov, the SP line of Deep-Blue-like supercomputers has emerged as a market leader.

These technologies and others are already generating as much as $25 billion annually for IBM—by one Horn estimate, anyway—and poised to do more. That amounts to nearly a third of IBM's 1998 revenues. John B. Jones Jr., an analyst with Salomon Smith Barney, says success stems from the high quality of IBM's research—and its ability to shed once-weighty bureaucracies and speed research advances into production. In semiconductors, for example, Jones says IBM is "bringing their technology to market faster than the competition—faster than Intel, faster than Motorola, faster than Texas Instruments, faster than Fujitsu." What goes for chips, he adds, goes for storage and other areas.

A few key factors account for this rejuvenation. One lies in the improved focus that comes from having survived hard times and being embraced by Gerstner and the business divisions. Pay raises, bonuses and other incentives—inside Research and company-wide—have been broadened to reflect a team-oriented approach to innovation.

But researchers and managers insist the biggest change is cultural. In the past, says Bernie Meyerson, "we never had the ability to do things in a timely manner around here." That was because people worried too much about protecting their own turf, he adds, putting up roadblocks to anything that threatened existing products. But that changed under Gerstner, he says. "Lou's emphasis is, 'Get the job done, I really don't care where you sit.'"



Basking in the glow: Research director Paul Horn is enjoying his division's rejuvenation.

Melding Many Machines

Mitch Stein is a big, bearded guy with an infectious smile. But confronted with the typical home entertainment center, answering machine or PC, he's not happy. Consider the gyrations necessary to navigate these supposedly user-friendly electronics—none of which easily go together. As senior manager of IBM's consumer systems and software group, Stein takes it personally. That's why he's exploring a concept he calls Life Networking, which seeks to blend computing effortlessly into people's everyday worlds.

In Stein's Watson lab "family room," phone messages and e-mail, TV viewing, Web-surfing and other aspects of home control are integrated onto a big television screen. Stein imitates a man returning home from work. His presence is detected, lights come on, and his dormant (but never off) system awakes. "Hello Mitch," the computer's voice greets him. "Several messages are waiting for you."

Although many other companies are experimenting with such systems, few have IBM's expertise in speech recognition, graphics, storage, processing power and electronic security *(see "The Couple That Computes Together," p.52)*. It was that extensive technical base, coupled with marketing clout, that brought Stein, Apple's former director of Human Interface Technologies and a founder of five startups, to Big Blue. At a smaller company, he notes, "I came to the realization that maybe, best case, I'd be able to do one or two point products. But I knew I would never be able to attack the whole platform."

Indeed, with the help of people like Stein, IBM is seeking to wield its arsenal to forge an era of "pervasive computing," where everything and everybody are electronically networked. And while most projects remain in the lab—including Stein's effort to

design a Life Networking-style home information center application—the company is already probing the market with a few early offerings.

Often, these are launched under its novel First of a Kind program, where researchers team with an adventurous customer to tackle specific problems in some unique way. The appeal for customers is to gain an early entry into a new technology. IBM gets to work out kinks in a controlled, real-world test bed. If things don't pan out in one year, the project is terminated. But if all goes well, the idea might be expanded dramatically, opening new areas of growth.

The fall 1996 introduction of continuous-speech-recognition software provides a prime example. The company worked with New York's Memorial Sloan-Kettering Cancer Center and Massachusetts General Hospital to produce MedSpeak, a specialized application for radiologists, whose distinct technical vocabulary made recognition easier. As the technology improved, IBM expanded into legal dictation and then general products—establishing its ViaVoice line as a speech-recognition force. Ongoing projects in 1999 include a PalmPilot-based electronic-shopping and data-mining system launched with England's Safeway supermarkets, and a disaster-management effort called TeamBuilder, developed with the city of Orlando to automatically identify and alert the personnel best suited to handle different emergencies.

Whether through such systems or something else entirely, computer technology seems destined to become more pervasive. But that begs another question: With the ability to create, access and transmit digital information increasing so rapidly, how can people possibly make sense of it all?

Deep Thoughts

One answer is what IBM calls "deep computing." The concept comes from Deep Blue, whose 1997 rematch victory over Kasparov resulted not only from massive computing power, but from dramatically improved chess-playing algorithms as well. It's that combination of power and approach, applied to vast amounts of data, that defines deep computing.

For IBM, the challenge goes far beyond fun and games. So this May, the company launched its Deep Computing Institute, an umbrella organization that pulls together 100-odd researchers at the Watson, Haifa, Tokyo and Almaden labs. By focusing these distributed talents in computing theory, statistics, computational biology, financial mathematics and data mining—expertise previously turned largely on scientific challenges—IBM wants to solve complex business problems.

One ambitious project under way this spring aims to combine Big Blue's supercomputer weather-prediction capabilities with energy and financial modeling to help utilities meet power demands more efficiently—even to the point of buying and selling excess capacity on spot markets.

It's a deep computing problem if ever there was one. IBM isn't known for weather forecasting. But Deep Thunder—an SP computer outfitted with 3-D graphics and powerful modeling algorithms—can often predict weather in localized areas with greater precision than anything available through government or commercial channels. The system debuted at the 1996 Olympics in Atlanta, where it aided the scheduling of sailing and other weather-dependent events—and helped save the closing ceremonies by predicting that a powerful storm would stay 10 miles from Olympic stadium.

Because weather is central to determining energy demand, even conventional weather forecasts can help utilities use their generators more efficiently. In a program with a midwestern utility that ended last year, IBM researcher Samer Takriti helped develop proprietary algorithms he says can trim 3 percent to 5 percent off generating costs—enough to save the typical utility upwards of $40 million annually. Add in Deep Thunder's capabilities, Takriti reasons, and the model could get even better; he's now working with Thunder researchers to do just that. At the same time, recent industry deregulation is spawning volatile energy markets—complete with futures, options and hedging strategies. So Takriti hopes to capitalize on IBM's years of modeling supply-and-demand dynamics and currency trading to create a system that accurately forecasts energy prices. The company believes the fusion of weather prediction and financial modeling could be applied to agricultural industries, property insurance and other fields.

Even as IBM redirects deep-computing resources from science to business, another vein of research focuses on mining the business of science. An especially hot area is computational biology, which involves

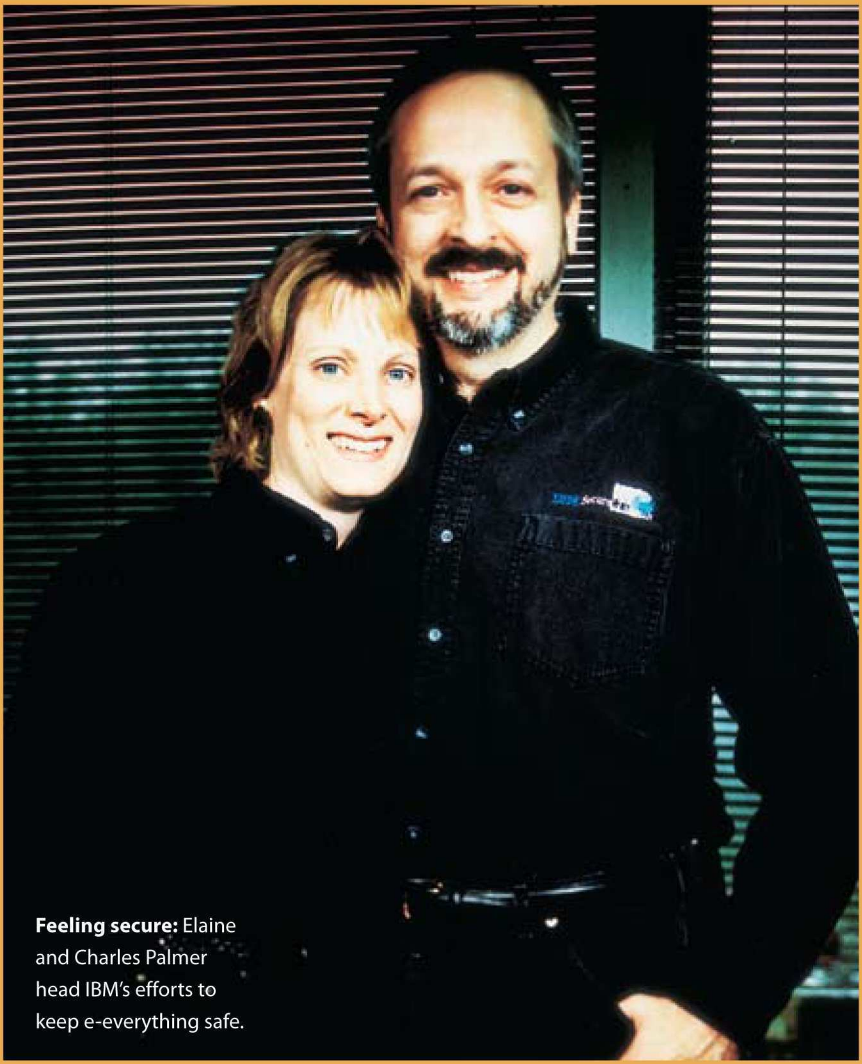
The World's Largest Industrial Research Organization

LAB (YEAR ESTABLISHED)	LOCATION	STAFF	CORE AREAS
Thomas J. Watson Research Center (1961)	Westchester County, N.Y.	1,700	semiconductors, math, physical sciences, computer science
Almaden Research Center (1986)	San Jose, Calif.	480	information storage, computer science, physical sciences
Haifa Research Laboratory (1982)	Haifa, Israel	280	applied math, computer science, multimedia, VLSI design verification
Zurich Research Laboratory (1956)	Rueschlikon, Switzerland	180	communications systems and technology, optoelectronics, computer security, physical sciences, computer science theory
Tokyo Research Laboratory (1982)	Yamato, Japan	170	software, computer science theory, networking, system technology
Austin Research Laboratory (1995)	Austin, Texas	40	advanced circuit design, microprocessor design techniques and tools
China Research Laboratory (1995)	Beijing, China	40	Chinese language and speech recognition, digital libraries
Delhi Solutions Research Center (1997)	Delhi, India	30	e-commerce, weather forecasting, deep computing, communications

In addition to this physical organization, Research is divided into five strategy areas that cut across geographical boundaries. Roughly equal in size and authority, the areas are: Services, Applications and Solutions; Computer Systems and Software; Telecommunications Technology; Storage Technology; and Systems, Technology, and Science. Increasingly, researchers form global teams that rely heavily on e-mail and Internet conferencing to converge on problems beyond the scope of operations at the individual labs.

Getting a grip: Mitch Stein aims to end the chaos in consumer electronics.

The Couple That Computes Together...



Feeling secure: Elaine and Charles Palmer head IBM's efforts to keep e-everything safe.

In 1975, Charles and Elaine Palmer were students at Louisiana State University. Charles handled student punch cards in the computer room. Elaine kept getting her programs wrong. After Charles repeatedly handed her cards back, she broke down and cried. Then, to Elaine's astonishment: "He actually leaped over the counter. He said, 'Don't worry, I'll help you.' So it's been love ever since."

Since that auspicious vault, the computer-science couple—married 22 years this spring—have been almost inseparable. After college both took jobs with Standard Oil of Indiana. In 1984, they joined IBM. Nine years ago, Elaine began dabbling in security issues—and a few years after that Charles founded the Watson lab's anti-hacker program.

These days, the two die-hard Louisianans—their license plates read "EATCAJUN" and SUTHNUH"—have offices across the hall from each other. Charles manages network security and cryptography. Elaine heads secure systems and smart cards. As IBM strives to shape a world of digital culture and commerce, computer and network security become increasingly important—whether it's halting hackers or preventing industrial espionage, the buck usually stops with the Palmers.

In soft southern drawls, the friendly couple explain that security is both a hardware and software problem. Charles oversees 18 researchers tackling the software side. One group—the "crypto ninjas"—works on things like data-protection algorithms and encryption keys. Another includes IBM's legendary "ethical hackers," who test security by breaking into computers and networks.

Perhaps the biggest effort, though, comes in creating evaluation tools and defenses like the Network Security Auditor, which scans for bugs and configuration flaws exploited by hackers and points out ways to fix them. Making these repairs prevents the vast majority of attacks. However, warns Charles, "there is no totally secure system, unless it's turned off and filled with concrete." As a complementary strategy, the group fashions intrusion-detection software like their recently released Haxor technology, which monitors networks for signs of attack and other suspicious activity.

No matter how good the electronic defenses, though, computer systems are also physically vulnerable. That's where Elaine comes in. "The key," she explains, "is the key." That is, an encryption system's password or numerical key, when stored on a server or some other hardware, turns that piece of equipment into a target. Attackers will drill through casings and insert hair-sized probes to download stored information. They'll even drop equipment into liquid nitrogen or zap it with X-rays—freezing any destruction mechanisms so they can get at the information inside.

To thwart such nefarious acts, Elaine's seven-person team worked five years to perfect the 4758 cryptographic coprocessor, a small metal box equipped with its own memory and processor that plugs into a server to perform cryptographic operations and store such sensitive data as encryption keys.

Under its metal exterior, the 4758 is wrapped in electroconductive mesh. If a probe strikes the mesh, it destroys all essential information. Temperature sensors, voltage meters and X-ray detectors do the same for other forms of attack. Explains Elaine, "It doesn't self-destruct in a Mission Impossible way, but it does destroy all the sensitive data inside."

Just before last Thanksgiving, the 4758 became the first product to pass Level 4 (the highest level) of the Federal Information Processing Standard for cryptographic devices. IBM envisions the $2,000 device as an e-business essential—protecting everything from digital postage meters to electronic check-writing systems.

So do the Palmers discuss security issues in their spare time? You bet. Charles says if he doesn't have a lead on a specific problem, Elaine will—and vice versa. "It's a networking thing," he says. "Some people have to go to conferences.... I just go home."

analyzing huge databases of biological information to unearth patterns that might point the way toward a new drug or a better crop. IBM dived into this blossoming field in the early 1990s and now has some two dozen researchers assigned to it, with scores more in related areas. One key hire was Barry Robson, who before joining IBM helped launch several computational-biology ventures and conceived a computer system instrumental in creating a test for mad cow disease. Now strategic adviser to IBM's Computational Biology Center, Robson says that through clinical drug trials and decades of genetics research, scientists have amassed stockpiles of biological data that today's powerful computers and sophisticated algorithms can finally begin to decipher. "My passion is to really see it become an everyday applied discipline," he adds.

IBM's biggest publicly announced effort—an agricultural genetics program launched with Monsanto in January 1998—revolves around Teiresias, an algorithm that can scour vast protein or gene sequences to find repeated patterns that might code for similar functions in different molecules. Monsanto hopes Teiresias, named after a blind seer in Greek mythology, will hunt through its proprietary databases and speed the identity of genes responsible for improved yields, higher nutritional content or pest resistance.

The initial deal concluded this spring. Under a new agreement that runs through 1999, IBM will also use the algorithm to look for patterns in the far larger public databases maintained by the National Institutes of Health and other government organizations. Beyond the discovery of new genes, the company hopes Teiresias will turn up unsuspected commonalities across protein families that will enable scientists to design drugs to attack a wide variety of ailments.

But Can Big Blue Boogie?

Shortly after taking over as research director in 1996, Paul Horn changed the division's motto. Out went the phrase, "famous for its science and technology and vital to IBM." The new legend simply declared: "vital to IBM's future success." Talk about shock. "He took science and technology out of the wording," recalls Randall Isaac, research vice president for Systems, Technology, and Science. "People were wondering, 'What does it mean, what does it mean?'"

While the motto change hardly raised eyebrows outside IBM, what it spoke to has dogged the company since the McGroddy days: science doesn't hold the place it once did. Cherry Murray, director of physical sciences at Lucent Technologies' Bell Labs, pulled no punches during a talk last December in Washington, D.C. "IBM lost 50 percent of its physics researchers. When you do that, what you had is gone."

Horn's people counter that axed basic science projects involved long shots like neutrino detection, which even if successful were unlikely to impact the company commercially. Meanwhile, Research continues to support fundamental studies in key areas of physics and materials science, as witnessed by its storm of semiconductors and storage advances and its explorations into quantum computing and other scientifically risky areas where gambling makes more sense. What's different from the past—the point of the new motto—is that science is no longer considered an end unto itself, says Isaac. "We still want to be famous in science and technology—but its goal is to be vital to IBM's success."

In this view, IBM has an ally in former research director John A. Armstrong. Before his 1993 retirement as vice president for science and technology, Armstrong was McGroddy's boss. What IBM has done, says Armstrong, is dare to ask, "How much is enough?" The finding that less science will do, he adds, "is deeply disturbing to the national scene." And though people chastise IBM for scaling back basic studies, he scoffs, "they don't scorn Intel for never having serious research. Same is true for Microsoft, same is true for Motorola."

In the end, far more serious than how much science to support are the straightforward challenges of staying nimble and creative inside a worldwide organization. Horn admits Research isn't as competitive as he'd like in networking and certain Internet technologies, though he won't specify which ones. But in attempting to beef up these areas IBM must battle the perception that it is stodgy, and, well, uncool.

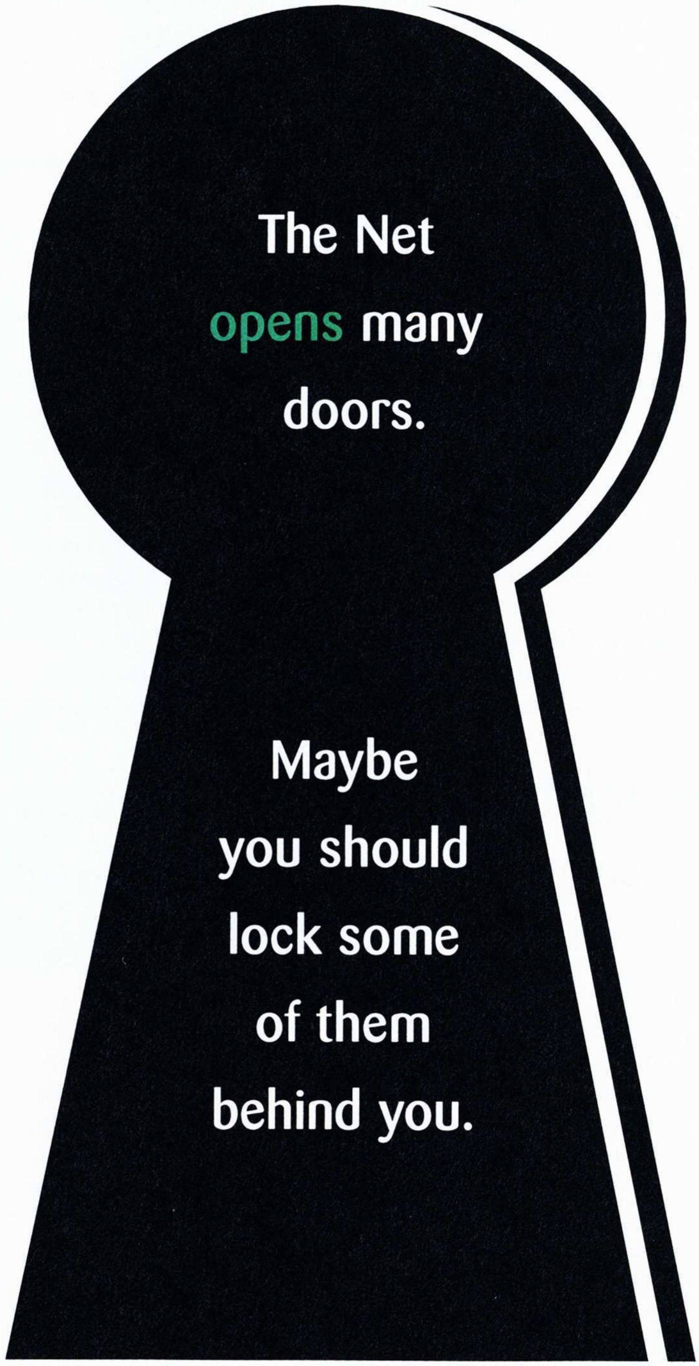
Since taking over, Horn has moved aggressively to address these concerns. To better compete with startups, an unprecedented number of researchers now receive stock options. A Watson out-building was turned into a gym. The Hawthorne lab got a new entertainment room—the Hawlodeck—rigged for video games, go and chess. In what would have been a sacrilegious act at previously teetotaling IBM, Research now hosts "Summer Fun Days" with live music, beer and wine. Horn's even hired an activities director to ensure summer interns have fun.

IBM dared to ask: "How much science is enough?" According to a former research director, many found the answer to be deeply disturbing.

Horn says that these efforts are beginning to pay off in improved recruitment. But at least some potential hires have a bigger question on their minds: Can radical ideas thrive in the new environment? Former IBM Fellow Jerry Woodall, now an electrical engineering professor at Yale University, thinks this is Research's Achilles' heel. In their zeal to bolster the bottom line, he says, managers have virtually eliminated curiosity-driven investigations in areas that don't relate directly to current business needs. Such projects, Woodall believes, could be vital in the future, "the high-tech corporation's equivalent to 'seed corn.'"

Gerstner himself had the chance to confront this issue last July, when Research treated 700 summer students to a day of music and brainstorming sessions held simultaneously at its labs around the world. At the Watson festivities, a young would-be recruit said he'd never come to IBM for fear that if he did do something truly different and important it would never see the light of day.

The chairman didn't miss a beat. Pointing out a curly-headed mustachioed figure in the crowd, he replied: "Ask Meyerson about that." ◊



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After a decade of calculations, the first wave of materials designed from scratch on the computer are ready to be made and tested. On the horizon: new substrates for optics and electronics.

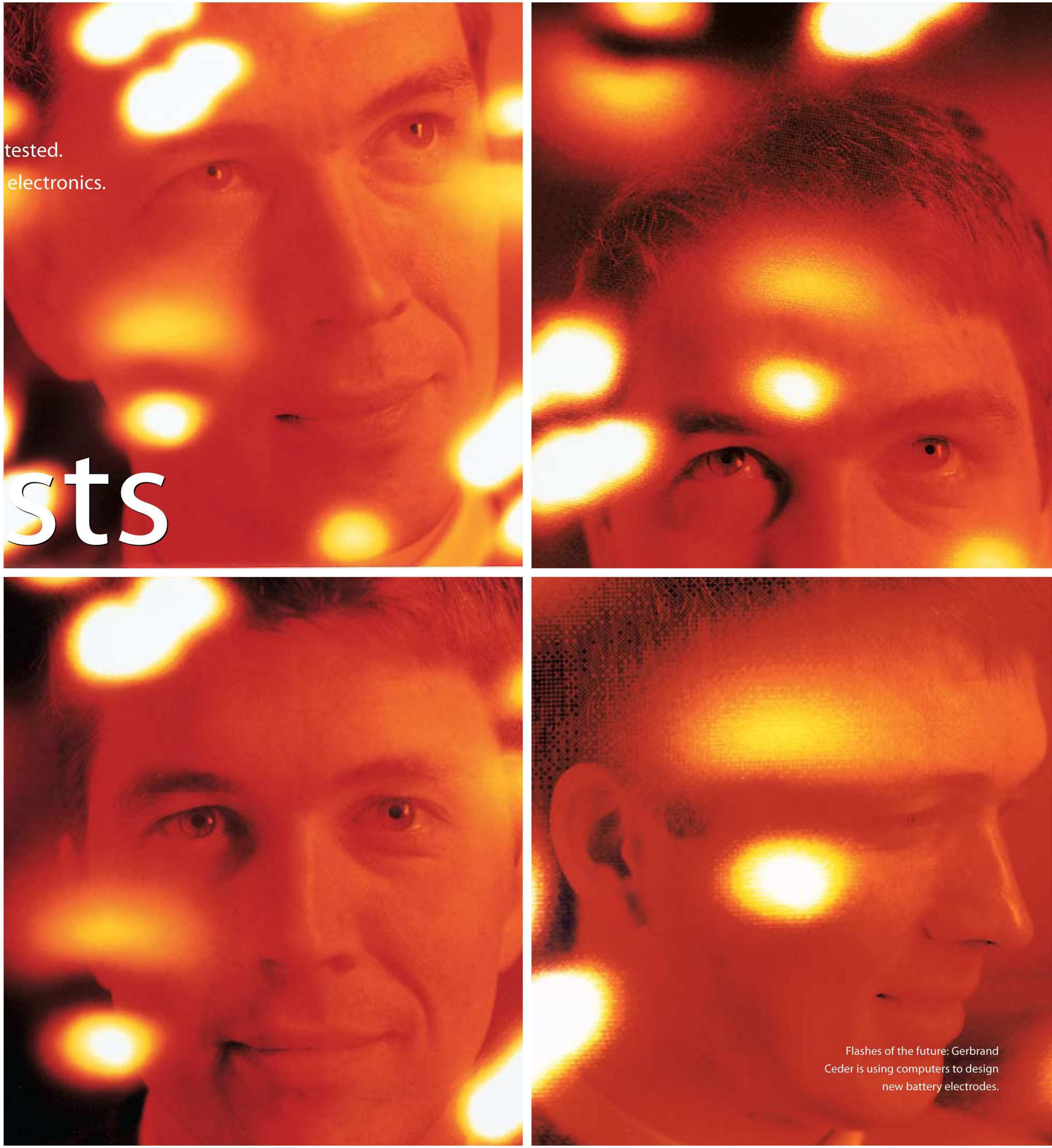
BY DAVID VOSS

The Virtual Alchemists

The first thing you notice about Gerbrand Ceder's materials science lab at MIT is that there are no crucibles, no furnaces, no crystal-growing instruments. Instead, you find a row of high-resolution computer displays with grad students and postdocs tweaking code and constructing colorful 3-D images. It's in this room, quiet except for the hum of fans cooling the computer power, where new high-tech ceramics and electronic materials that have never been seen or made before are being forged. They are taking form "in virtuo"—designed from scratch on the computer, distilled out of the basic laws of physics.

The next thing you're likely to notice is how young Ceder is. Quick to laugh but intensely passionate in explaining his work, the 33-year-old associate professor is one of a new breed of materials researchers, trained in traditional processing techniques, who have turned to discovering materials using computers. The dream is simple: Replace the age-old practice of finding new substances by trial and error, with calculations based on the laws of quantum mechanics that predict the properties of materials before you make them.

PHOTOGRAPHS BY FURNALD/GRAY



Flashes of the future: Gerbrand Ceder is using computers to design new battery electrodes.

You can, in theory at least, design metals, semiconductors and ceramics atom by atom, adjusting the structure as you go to achieve desired effects. That should make it possible to come up with, say, a new composition for an electronic material much faster. Even more important, tinkering with atomic structure on a computer makes it possible to invent classes of materials that defy the instincts of the trial-and-error traditionalists.

It's an idea that has been kicking around for at least a decade. But with the explosion in accessible computer power, as well as the development of better software and theories, it's becoming a reality. Last year, Ceder and his collaborators at MIT synthesized one of the first materials that had actually been predicted on a computer before it existed. This new aluminum oxide is a cheap and efficient electrode for batteries. And while it may or may not lead to a better, lighter rechargeable battery, the success of Ceder's group—and related work at a handful of other labs—is proving that useful materials can be designed from the basic laws of physics.

Designing from first principles represents a whole new way of doing materials science, a discipline that Ceder describes as "a collection of facts with some brilliant insights thrown in." It's a transformation he's been aiming at since his undergraduate days in the late 1980s at Université Catholique de Louvain in Belgium. "My background is heat and beat metallurgy," he explains. "But I always thought there should be more to it, some way to calculate things using all the great physics of quantum mechanics."

By tinkering with atomic structures, you can invent materials that defy the imaginations of experimentalists.

Getting there, however, won't be easy. Scientists have known for decades that, according to the rules of quantum mechanics, if you could detail the position of the electrons swarming around atoms, you could then calculate physical properties of the material. Yet the sheer difficulty of carrying out these calculations has made the task seem hopeless. The computations are hard for even one molecule, but for the huge numbers of atoms that make up even the smallest chunk of a solid material, the chore is truly intimidating.

In the search for new vaccines and drugs, where computer-aided design *has* taken off, progress has been achieved precisely because the designers have been able to skip the influence of particular electrons, along with the rigorous quantum calculations. But inorganic materials are tougher. The properties of metals, alloys, semiconductors and oxides result from a vast sea of interconnected atoms and electrons. "With metals and ceramics, we really need to include the electrons as active players," explains Erich Wimmer of Molecular Simulation, a software company that markets molecular and materials computer modeling programs. "And that means we need quantum mechanical methods."

The linchpin of quantum mechanics is the Schrödinger Equation, which describes how electrons arrange themselves around atoms and how atoms share electrons to form chemical bonds. The Schrödinger Equation generates a "wave function" giving the probability that an electron will be at a given location at a given time. What makes it so powerful is that the wave function can reveal physical properties of the system: energy, optical absorption, conductivity. If done right, you insert the atomic masses and crystal structure, and out pops the physical properties of the material. The calculations are called "first principles" or "ab initio" because you start with the most fundamental information about the atoms and use the most basic rules of physics. The price researchers pay for this ability is that the Schrödinger Equation requires immense computer power to solve, even for simple atomic structures.

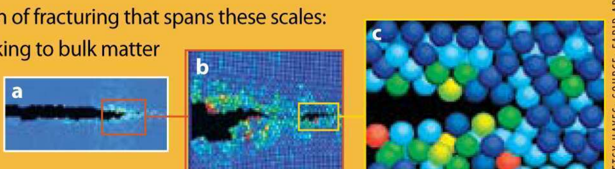
The Right Stuff

EIGHT YEARS AGO, CEDER SHOWED UP at MIT (he received his PhD from the University of California, Berkeley, in 1991) as a newly minted professor ready to give the Schrödinger Equation a

Cracking a Tough Problem

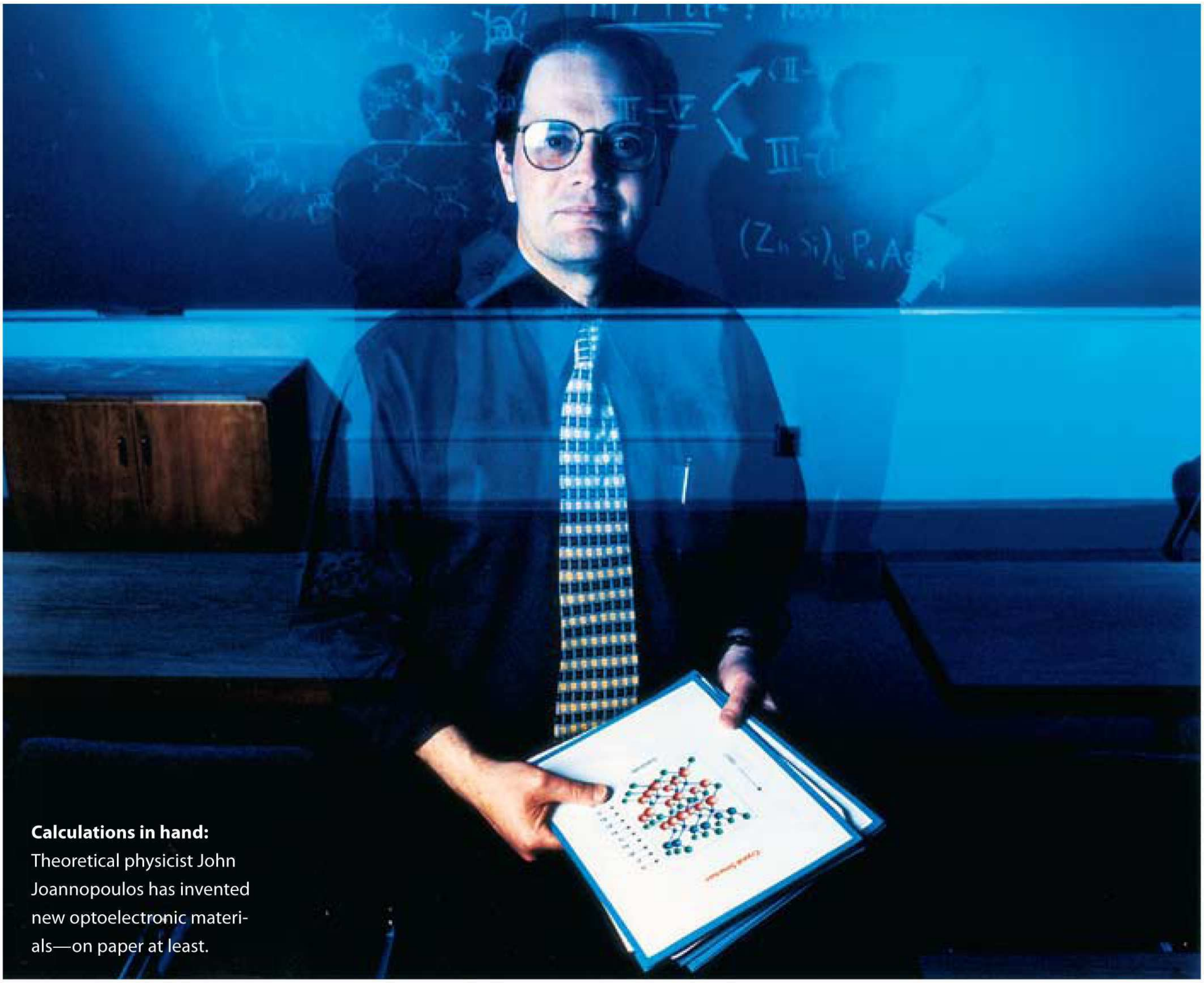
A fracture in metal may seem like a simple thing. But for materials scientists, understanding how cracks propagate is one of the grand challenges of computational research. Answers could help save billions of dollars now spent each year on repairing everything from airplane fuselages to turbine blades. But computationally explaining dynamic processes in materials, such as the formation of a fracture, is extraordinarily difficult because the events happen across vastly different lengths.

At Harvard University, Efthimios Kaxiras, an associate professor of physics, is collaborating with researchers at the Naval Research Laboratory and Farid Abraham at IBM's Almaden Research Center, to develop a description of fracturing that spans these scales: from chemical bonds breaking to bulk matter vibrating.



BETSY HAYES; SOURCE: FARID ABRAHAM

A crack in a solid is shown in (a). In this view, the solid is described by classical mechanics; the structure of the atoms is not considered. At the mesoscopic scale (b), a certain amount of information about the atomistic structure is taken into account, such as the material's crystal structure. In (c), the microscopic regime, the atomistic structure is described using quantum mechanics. Properties that occur on a larger scale, such as fracturing, are analyzed by looking at how individual atoms behave; but since only a relatively small number of atoms can be modeled, only a relatively small region of the material can be looked at in this way. The information must be effectively incorporated into the mesoscopic description. In turn, that analysis must be incorporated in the macroscopic picture.



Calculations in hand: Theoretical physicist John Joannopoulos has invented new optoelectronic materials—on paper at least.

try on one of materials science's most pressing problems: better batteries. Today's frenzy for cell phones and laptops has driven the quest for lighter and more powerful storage materials. Lithium cobalt oxide is the electrode of choice for lightweight high-power applications, particularly products like cell phones. But lithium is expensive—and cobalt is even pricier. The costs can be passed on in high-tech gadgets like cell phones and laptops but for other uses, such as powering electric cars, it's prohibitive.

Several of Ceder's MIT colleagues began working on an improved battery. But it was obvious they needed better, cheaper oxide materials to serve as the electrodes. The traditional materials science strategy would have called for mixing up a batch of an oxide and then adding and subtracting components a little at a time. But there are almost unlimited combinations of ingredients you can put in—and every ingredient affects every other ingredient. "Every time you make a chemical change, lots of other things get altered too," explains Ceder. "There may be structural changes, and who knows what else."

Ceder attacked the problem by creating the samples and testing them not on the bench, but on the computer. "The advantage is that you have full control over what you do," he says. "If I take a crystal, and add a little bit of some element, I can see exactly how the electrical conductivity will change." Systematically changing the electrode composition, Ceder used his software code to calculate the effects on battery voltage. By replacing the cobalt with titanium, or vanadium, could they get a peppier energy cell?

What they found was surprising. The voltage didn't depend strongly on the cobalt. In fact, the voltage was highest if all the cobalt were replaced with aluminum. This was entirely unexpected, Ceder says, because aluminum had been thought to be a nonplayer in battery oxides. But there was a hitch. Lithium aluminum oxide is an insulator. So even though the numbers showed the voltage would be at a peak, there would be no way to run a current through it. Calculations indicated, however, that a mixture of cobalt and aluminum might just do the job: enough cobalt to keep the electrode conductive, and aluminum to replace the rest.

That, at least, is what the computer showed. Someone still had to make the stuff. Enlisting the help of MIT ceramists, Ceder and his colleagues developed methods to synthesize the predicted cobalt-aluminum electrodes—materials that had never been made before. It turns out that, in fact, the mixture of cobalt/aluminum gives a higher battery voltage than cobalt alone. At the same time, the aluminum lowered the overall weight of the material, so that the energy density—another important figure for a good battery—went up, and the projected cost of the material went down.

Arranged Marriage

DON'T EXPECT TO FIND COBALT-aluminum electrodes in a battery anytime soon, however. Although

Phantom materials: Efthimios Kaxiras' tiny silicon clusters could revolutionize microelectronics. But can they be made?

the new battery material is superior in voltage and costs to conventional electrodes, the conservatism of the power-storage business means that it's not likely to be commercialized in the near future. Still, the success of Ceder's group marks a significant advance because it means a material has been designed on the computer and found actually to have the predicted qualities.

Scientists are far from being able to plunk themselves down at a keyboard, tap in some desired properties, and have a new substance pop out. Ceder points out that electronic and optical properties are relatively amenable to calculation, whereas other important characteristics, like hardness or corrosion resistance, are more difficult to compute. Those properties, for one thing, depend on events occurring over a wide range of size and time scales (*see "Cracking a Tough Problem," p. 58*). "There are still a lot of problems you can't address by these methods," he says.

For now, though, the rewards of finding novel electronic and optical materials are more than enough to keep top materials researchers interested. A few dozen meters from Ceder's lab, another MIT group, headed by theoretical physicist John Joannopoulos, believes it has solved one of the toughest puzzles in semiconductor research—providing a material bridge between electronics and optics.

Such a connection could make it possible to build silicon-based semiconductors that are able to carry out optical-based operations. But getting there means mating silicon with stuff that has favorable optical properties. And from a materials science point of view, there is a major hurdle: Optical and electronic materials tend to be incompatible. "Silicon is great for making electronic circuits, but it has lousy optical properties," says Joannopoulos. "Things like gallium arsenide that have good optical properties hate to be stuck on top of silicon."

The reason is that the best optical materials for the part of the spectrum that industry is interested in—around wavelengths of 1.5 micrometers—have atomic spacings that don't match silicon. So, if you grow gallium arsenide on silicon, the mismatch causes havoc in the interface—stress, strain and defects galore. This situation presented a unique opportunity for design-from-first-principles, says Joannopoulos. "We asked ourselves, could we take the specifications and design a material to meet them?"

The answer: yes. The timeframe: a decade of difficult calculations. The solution involved a recipe for putting layer after layer of different elements down on a silicon surface, each layer from a different group in the periodic table. If the approach had been tried experimentally, it would have involved an almost unlimited number of combinations, and each batch would have to have been synthesized and tested. Instead, Joannopoulos and his co-workers did extensive *ab initio* calculations on the computer to nail down the optical properties and the atomic spacing.

This year, grad student Tairan Wang finally hit on a layering scheme that created a new material with the right structure to join smoothly with the silicon surface and still act as an optical material. By putting down arsenic, zinc, silicon and phosphorus in just the right order—on the computer, of course—he was able to hit the target. "The main thing is we've identified a class of compounds," says Joannopoulos, "so if this particular one is difficult to fabricate, we can try another that will also meet the specifications."

Once you've cleverly designed something on a computer, you still have to find a willing experimentalist to make the stuff. In the case of Joannopoulos' new optoelectronic material, the problem is that nobody has a synthesis setup that can spray the atomically precise layers of the four different elements. But after a decade of struggling to find the right structure, Joannopoulos isn't worried. He says a couple of labs are interested. And he expects to get to work soon on actually making the material.

Scientists are far from being able to sit down at a keyboard, tap in some properties, and have a new substance pop out.

Playing God

WHATEVER THE EVENTUAL VALUE of these computationally designed materials, the work is unquestionably opening up researchers' imaginations. Like Ceder, Efthimios Kaxiras is one of the new generation of materials researchers more skilled in computational physics than in firing up a laboratory kiln. An MIT graduate and former student of Joannopoulos, Kaxiras is now an associate professor of physics at Harvard University, where he is dreaming up materials that no one has ever seen.

In one such research project, Kaxiras is envisioning tiny clusters of silicon atoms that could perform useful tasks. "When you take a few hundred atoms of something, it behaves very differently than the bulk material," he says. In thinking about how silicon atoms bond, Kaxiras came up with a new structure containing a mere 45 atoms. "These 45 silicon atoms form two mirror-image structures," he explains. "And if you could figure out how to induce one to change into the other, you could have a tiny switch."

Clearly a switch only 45 atoms big would make circuit designers delirious. By comparison, there are hundreds of thousands of atoms in each of today's smallest circuit elements. But the silicon clusters remain very much in the realm of the virtual imagination. Says Kaxiras, "Nothing is known about these structures. I came up with them by thinking of the possibilities, and then I fed the structures into the computer to learn more about their stability and physical properties." Kaxiras says more experimental work is needed to know even whether these structures actually can be created.

"It's really hard playing God," says Joannopoulos of his 10-year quest for novel optoelectronic materials. Indeed, designing new materials from scratch using the basic laws of physics is, in many ways, more demanding than the trial-and-error approach to finding substances. It requires unconventional thinking about materials and the skillful use of a computational tool kit that is only now being developed. But if this new breed of researchers succeed, they could be on the verge of creating a whole new materials world. ◊

Sweet smell of success?
CEO Steven Sunshine leads Cyrano Sciences' efforts to sell a vapor detection system.

A Nose for Business

What's the difference between Chanel No. 5 and Chanel No. 19? Ask Cyranose 2000, an artificial proboscis that's sniffing out the market.

BY ILAN GREENBERG

THE STRANGE SCENT-DETECTION DEVICE DEMONSTRATED BY THE SALES TEAM FROM Cyrano Sciences looked a little like a candy-colored cell phone. But to the nurses at the University of California, Los Angeles Dental School, it seemed as beautiful as a mouthful of perfectly capped teeth.

A program at the Dental School was testing remedies for oral malodor—in other words, chronic bad breath—and the nurses were taking turns monitoring patients' progress. The methodology was simple: Nurse puts nose to patient's mouth, then everyone breathes deeply. Professionalism aside, no one involved walked away savoring the experience.

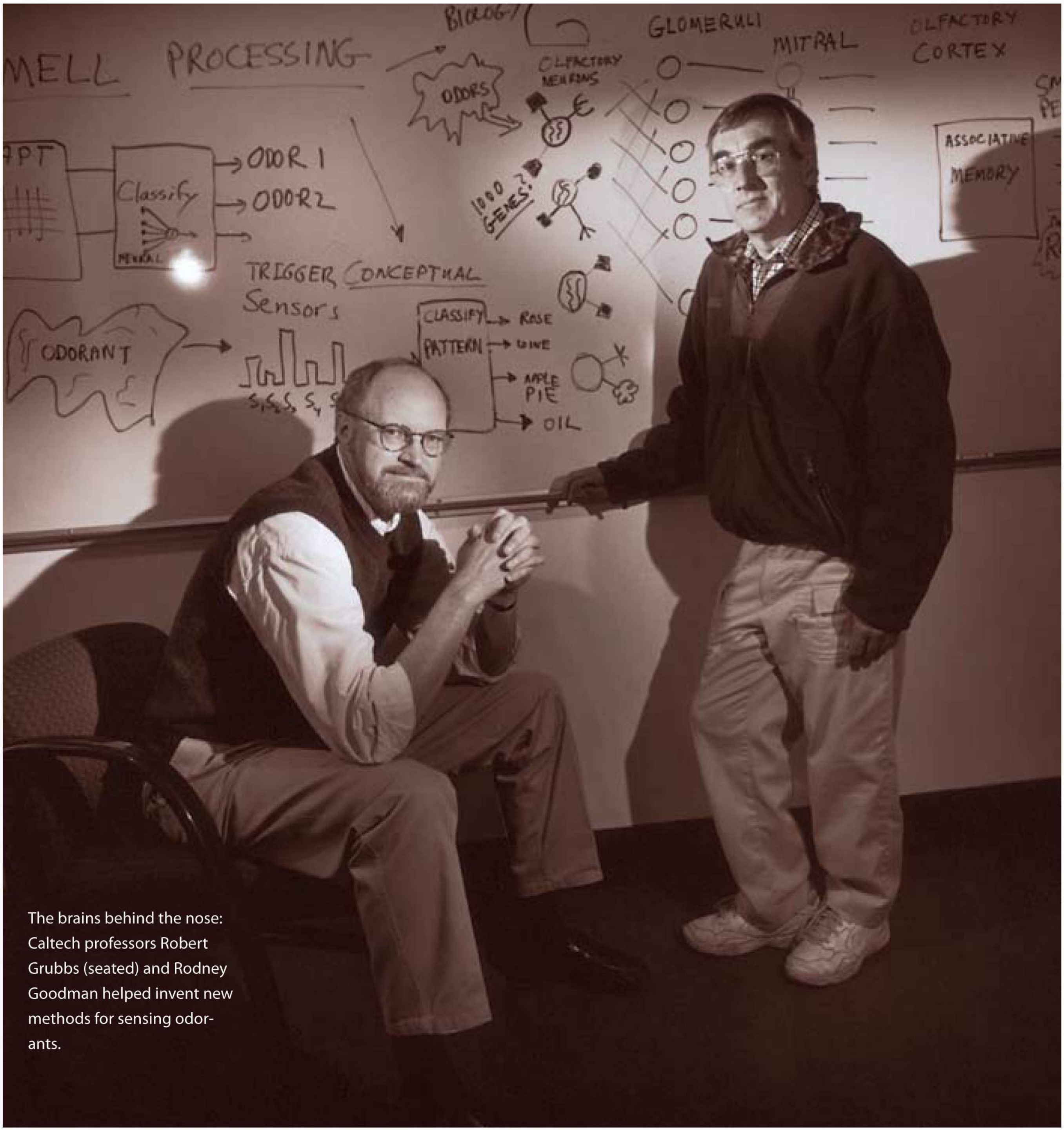
Why not try the Cyranose 2000 instead? According to Steven Sunshine, the earnest, 38-year-old president and CEO of Cyrano, his company's handheld detector promised not only a welcome reprieve for the nurses but also vastly improved accuracy in halitosis research. A smell, after all, is really just an individual's subjective experience of airborne chemicals known as odorants. Far better, according to Sunshine, to quantify the aroma in question by relying on the Cyranose 2000's 32 precise sensors.

PHOTOGRAPHS BY BROMBERGER & HOOVER

As a sales pitch, it was a slam-dunk. Unfortunately for Cyrano Sciences, marketing its new electronic nose to other prospective customers won't be half as easy. The company, a startup staffed by chemistry PhDs and electrical engineers eager to make their mark in business, faces a customer landscape studded with skeptical purchasing managers, disparate technological requirements and the simple fact that the world has thus far been doing just fine without an electronic nose. From the food industry, to animal husbandry, to contraband law enforcement, the lab-rats-turned-entrepreneurs at Cyrano Sciences must tackle head-on the single most treacherous challenge for many startups after the initial phase of product development: inventing a market.

CONJURING DEMAND OUT OF whole cloth is common currency for pioneers in any industry. Apple Computer stared down the challenge in the early 1980s. Consumer goods titans such as Procter & Gamble and Gillette regularly create demand for newfangled items by virtually inventing a mass culture of desire with hundreds of millions of dollars in annual advertising. Today, life for some would be next to unlivable without triple-bladed razors and 500-megahertz personal computers. Soon, we may not be able to get by without our smell machines. At least, that's the plan.

With the launch of the $5,000 Cyranose 2000 slated for this fall, Sunshine and company are setting out to sample the waters in two trial markets: detecting "off" odors in packaging materials, and quality control testing of raw materials such as soda concentrates for the food industry. Cyrano will face entrenched competition from both high-end, specialty analytical instruments as well as from what might be termed an installed base of human noses. Specifically, the device will have to out-sniff profes-



The brains behind the nose: Caltech professors Robert Grubbs (seated) and Rodney Goodman helped invent new methods for sensing odorants.

sional teams of olfactorily acute individuals known as human "sensory panels" employed by consumer goods makers. (Facing a related dilemma, Scott Cook, the co-founder of personal accounting software leader Intuit, once quipped that his toughest competitor was his customers' stock of pencil and paper.)

THE TECHNOLOGY BEHIND THE Cyranose 2000 is the brainchild of a chemist named Nathan Lewis at the California Institute of Technology, who in 1993 began pondering the workings of the human nose—an organ responsible for what is arguably the most versatile and least understood of the five senses. Lewis, along with then-postdoc Mike Freund, decided to design a synthetic sniffer. The strikingly simple solution they hit upon *(see diagram, p. 67)* entails doping ordinary polymer plastics with particles of a conductive material, such as carbon black. Painted onto a ceramic surface, electrons move through such composites at a predictable rate. But expose it to an odorant, and the plastic starts absorbing vapor molecules and swells like a sponge. Because the swelling alters the spacing between the conductive particles, it creates an easily measured change in the composite's electrical resistance.

firms that had been attempting to sell artificial probosces. But partly because of their high cost, these instruments had found little success and today the electronic nose market still remains puny at less than $15 million per year.

Lewis believed his approach was more versatile than the British system and, because it was so simple, would also be very cheap to manufacture. After building a prototype system with the help of Caltech chemistry professors Robert Grubbs and electrical engineer Rodney Goodman, the device's commercial potential began to crystallize. Lewis was issued a patent in 1995, and it wasn't long before a a physician-turned-venture-capitalist named Seth Harrison began sniffing around the Caltech labs. By April 1997, Cyrano Sciences had been formed with the university's blessing, a license to the electronic nose patent and Harrison as interim CEO.

TAKING OVER THE KIND OF GRAY, nondescript warehouse in suburban Pasadena that even longtime neighbors never really notice, the company began hiring a product development team, mostly chemists and other materials scientists. For more than a year and a half, the researchers fabricated arrays of organic polymer sensors,

KEVIN KNIGHT

Money man: Venture capitalist Seth Harrison saw a business in olfaction.

Nose chips could be integrated into many consumer products, for instance, a microwave oven that would tell you when your dinner is ready to serve.

As it turns out, every type of plastic has its own unique chemical likes and dislikes. Some readily absorb oily vapors such as benzene, others prefer water. By creating an array of sensors, each from a different plastic, Lewis was soon able to generate a distinct electronic pattern for every odor. The next step was to record the patterns that different smells induced in the sensor array. Once trained, this "nose chip" could recognize fragrances it had been exposed to previously and determine when they changed.

Lewis learned that similar technology had already been invented by scientists in the United Kingdom, who had started their own company, AromaScan. In fact, the Brits were just one among a half-dozen

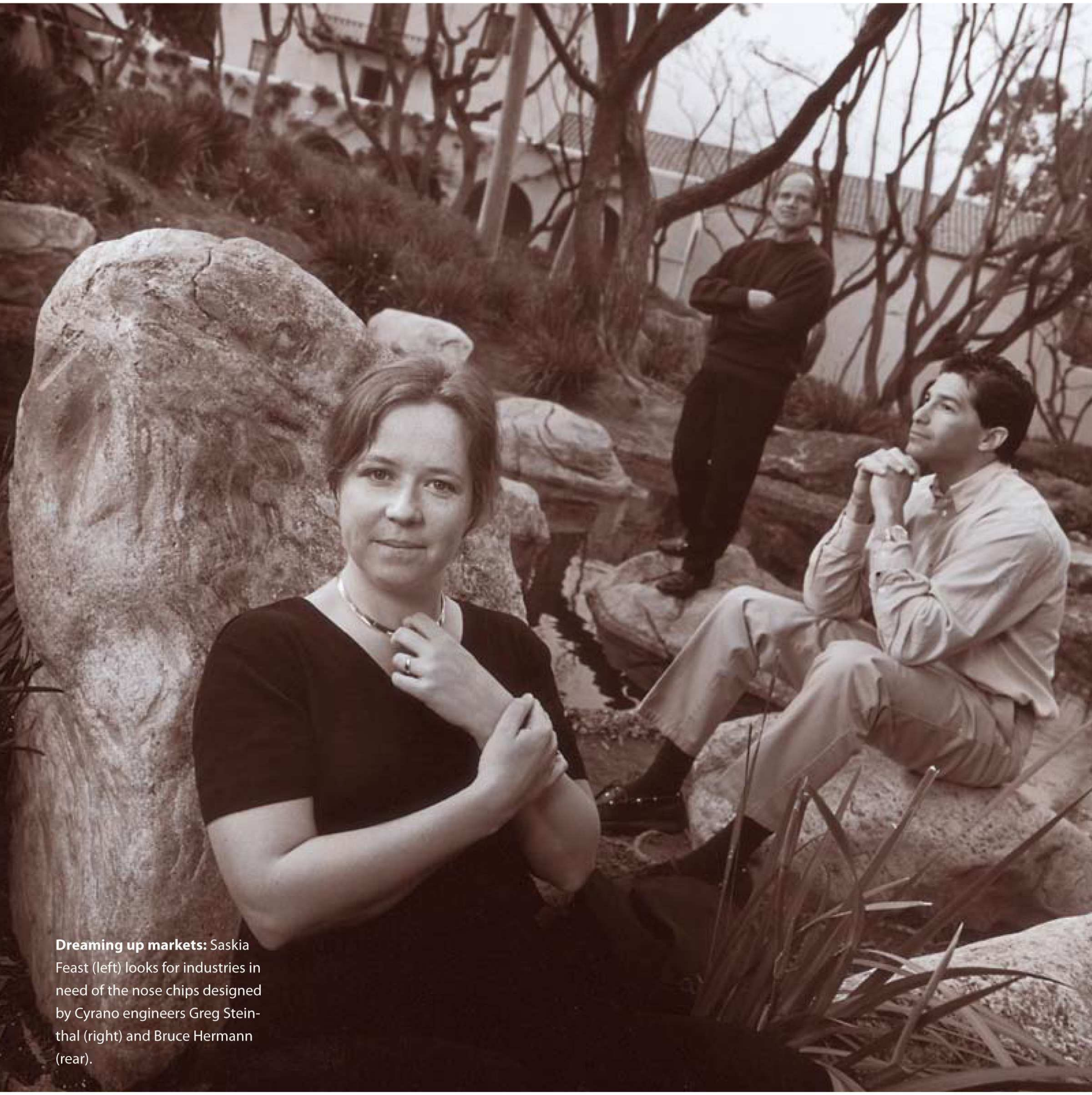
wrote software to recognize the electrical "fingerprints" yielded by individual vapors, and built a dizzying number of plastic-molded prototypes. The engineering team endlessly tested the nose-chip designs against various women's perfumes. "Our goal, which we eventually accomplished, was to get it down to where it could detect the differences between Chanel No. 5 and Chanel No. 19," says Greg Steinthal, head of the engineering department.

The quasi-academic environment and dearth of business-types were part of the strategic plan put in place by Cyrano's venture backers, who have been in control of the company since its inception. "Too many MBAs in an early technology development program might lead you in the right business direction, but they won't understand the real technology issues. That can throw off the corporate timing," says Harrison, a general manager at Oak Investment Partners in Westport, Conn., which, along with Johnson & Johnson's investment arm and Marquette Venture Partners, has so far pumped $12 million into the enterprise.

While basic science and engineering remained the task at hand, the company made an effort to hire people with commercial experience—especially aspiring entrepreneurs languishing in large corporations. Steinthal was brought in from Telaire Systems, where he had already helped push a carbon dioxide sensor to the market. Sunshine was hired as chief of R&D from manufacturing giant Raychem, where he'd led an in-house incubator. According to Sunshine, the common denominator among his colleagues is "knowing when to stop researching." (Little wonder that Lewis and the other Caltech inventors had chosen to stay put in academia.)

BY THE BEGINNING OF THIS YEAR, with most of the kinks worked out of the device, Cyrano was ready to make the seismic shift to an enterprise focused on the unscientific domain of salesmanship. Sunshine was promoted from research boss to CEO and began recruiting a marketing staff thick with technical backgrounds.

A key hire was Saskia Feast, a British chemist whom Sunshine gave the title of technical marketing manager and tasked with sizing up potential customers. Up until this point, the nose's creators and investors had been doing plenty of daydreaming



Dreaming up markets: Saskia Feast (left) looks for industries in need of the nose chips designed by Cyrano engineers Greg Steinthal (right) and Bruce Hermann (rear).

about applications (busting drug dealers, diagnosing cancer) and had come up with a laundry list of some 20 potential markets. But which were most likely to make the jump to the unfamiliar nose-chip technology? Feast has been boning up on a score of industries in order to find out.

She began by identifying 73 large prospective customers, and is now grading them on a scale from "one" to "five," depending how on difficult the sale looks. The fives are the toughest, Feast says, and include heavily regulated businesses where new technology means risky change, and electronic noses are eyed with suspicion. For instance, in the chemicals industry workers assess accidental spills by breaking a sample down into its chemical subcomponents, then analyzing each part. Cyrano's argument is that the industry could skip this detailed analysis if it knew roughly what spills contained—something the nose chip could do with one whiff. But the chemicals industry isn't used to diagnosing blended elements and Feast expects Cyrano's message will be hard to get through.

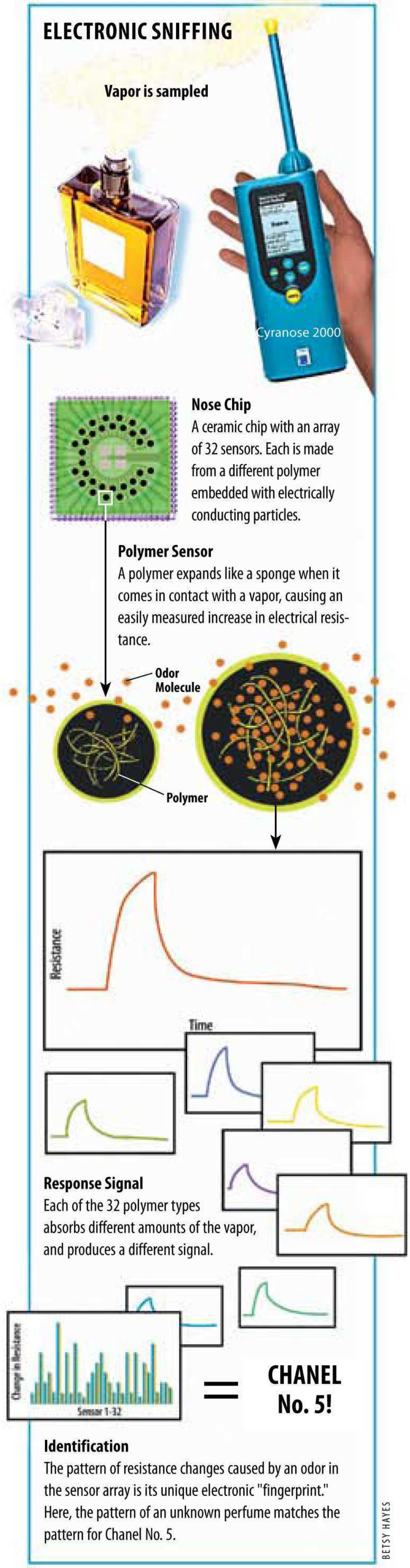
For reasons that are hardly mysterious, food companies represent the overwhelming number of zeros and ones in

Feast's database. The industry, she says, "is filled with people very familiar with using smell" to detect spoiled food. Real noses, however, while quite precise, are attached to people who aren't perfectly engineered for the job: They get cold and tired, and lose their edge after repeated contact with similar odors. But even the food industry is no easy sale: It's been burned before by firms promising dazzling smell detection and not delivering; Cyrano is pegging its hopes for a marketing knockout on an industry not entirely eager to get back into the ring.

WITH A LARGE, FRAGmented market full of companies ready to turn up their noses at newfangled technology, Feast's strategy is to seed the machine among "opinion influencers" in their industries, such as Kraft Foods and DuPont. The hope is to convert these key customers into nose chip evangelists. The same goes for the company's academic allies: Cyrano is a member of the Monell Institute's Chemical Senses Center, as well as the Media Lab at MIT. "The idea that we're a flash in the pan is something we always have to deal with," says Bruce Hermann, director of applications engineering, and a force in the company's marketing efforts.

The search for stability has also led Cyrano into what Hermann terms "a delicate dance" with a predatory competitor. In March, Cyrano signed a pact with Hewlett-Packard to jointly develop new versions of its electronic nose and collaborate on marketing. The scientific instrument giant already sells a vapor detection device of its own, a hulking, refrigerator-sized appliance called the HP 4440A Chemical Sensor, priced at $80,000.

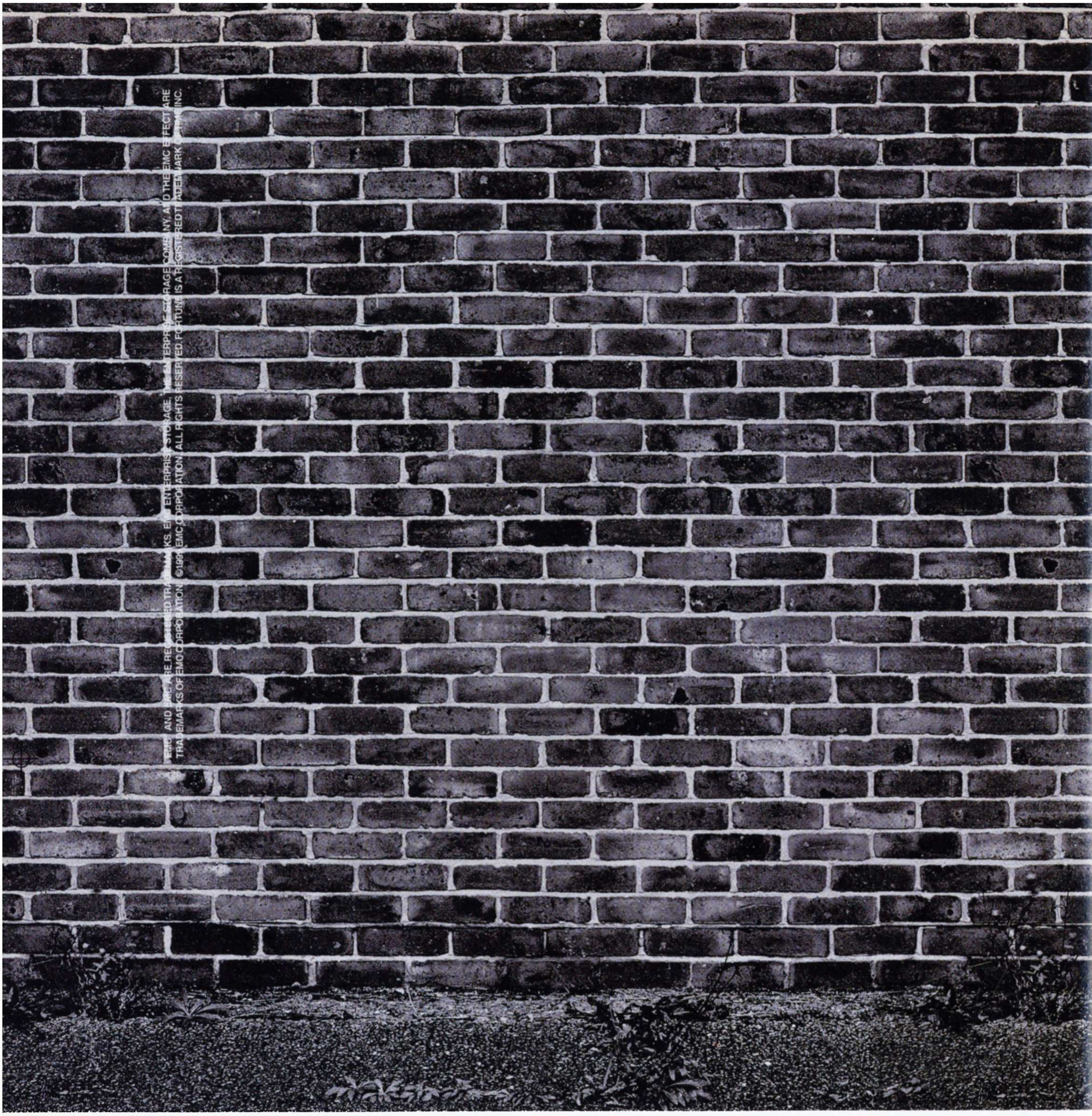
Cyrano brings to HP's table a technology that might turn out to be a "category killer." The deal's potential benefits for Cyrano are enormous, giving the company instant clout with potential customers and bolstering its reach into new sales channels. But HP's ultimate intention is something of an unknown, and there's no hiding the risk for Cyrano. Even the folks at HP don't shy from pointing it out. "Collaborating with HP is a two-edged sword for them," observes Mary Pat Knauss, future products marketing manager at HP's Wilmington, Del. facility.



The pact gives Cyrano "a stamp of credibility" but also holds the risk of terminally narrowing the smaller firm's future. Losing its identity in HP's embrace could mean becoming just another supplier for a line of odor detectors carrying the HP logo. Sunshine suggests his firm might follow Intel's lead and settle for a "Cyrano Inside" sticker. He's only half kidding, because in fact Cyrano does plan to engage in what Sunshine calls "chip-based design," a.k.a. electronic nose as universal electronic component. Sunshine imagines the nose chips could be integrated into many consumer products, for instance, a microwave oven that knows when food is cooked. Or firefighting equipment that can tell the nature of a blaze—chemical, electrical or arboreal.

Leaving the marketing to HP or another company would also allow Cyrano's engineers to do what they seem to love best, which is solving problems. Already the hunt for new applications has taken company officials as far afield as a Pennsylvania dairy farm, where the electronic nose holds promise for sensing which cows are in heat and ready for artificial insemination. (Currently, farmers use a bull, often leaving the animal in a state of homicidal frustration.) Cyrano is also studying how well their nose can mimic human sensory values. That is, they're teaching it to tell bad smells from unacceptably bad ones. An ongoing project with the Los Angeles Municipal Sanitation Department looks to size up the stink from sanitation leaks.

The work of forging new markets for a new product is not, it seems, totally unlike olfaction itself: both are endless, episodic trails of new experiences, not all pleasant. Standing in front of a blank whiteboard in Cyrano Sciences' expansive warehouse-office, Sunshine talks about how he now spends most of his time—preparing for the product launch and hunting for money. With a "substantial" burn rate (the amount of cash the company inhales each month without earning any revenue) Sunshine is busy raising a second round of financing. He's confident he will secure it, but the stress of running the company shows in his boyish features. Just then, someone enters the room carrying one of the brightly colored Cyranose 2000 prototypes. Suddenly, Sunshine's eyes cease blinking and his face takes on the look of someone who can detect the sweet smell of success. ◊



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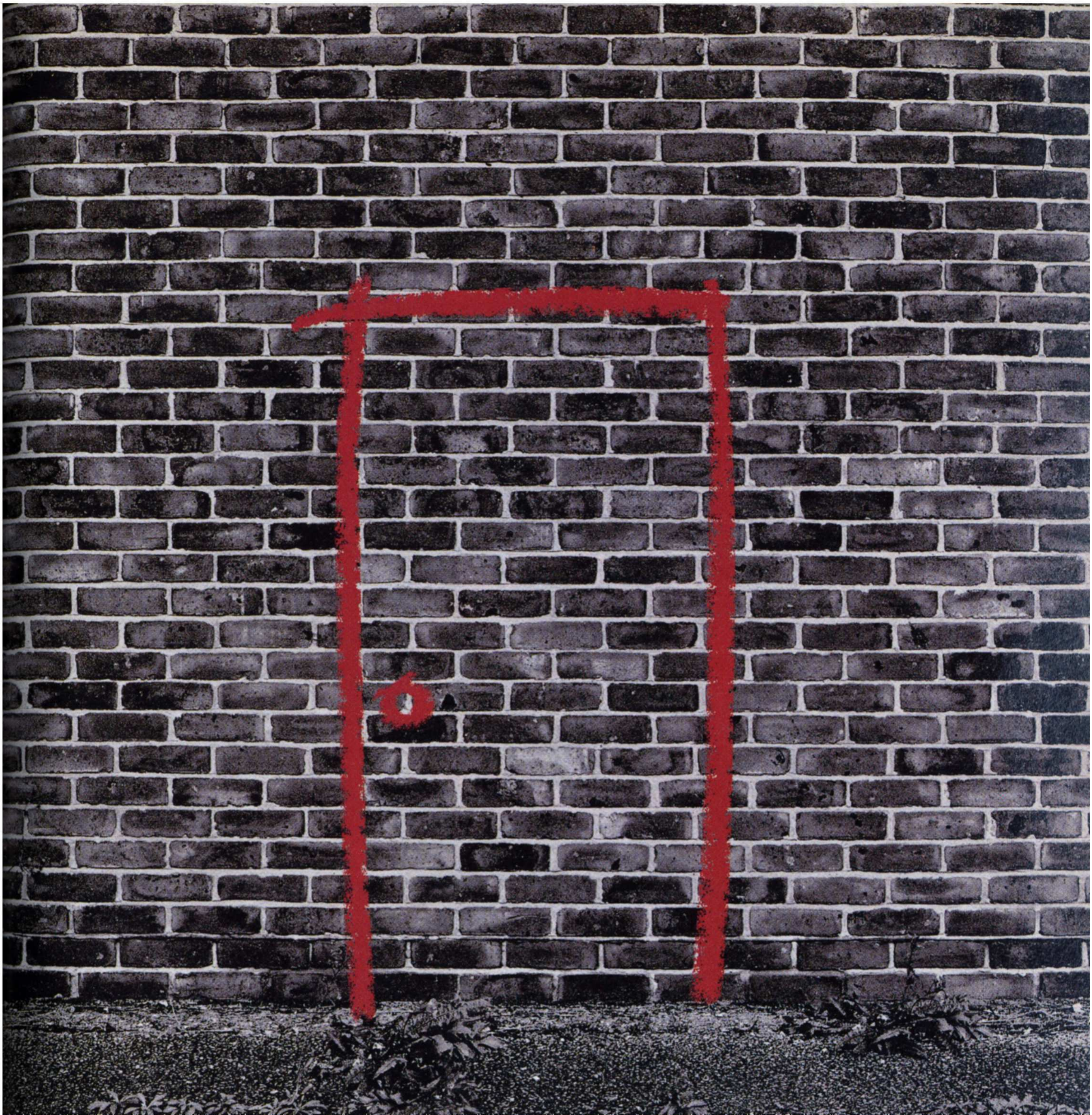


After 20 years of plodding development, the Global Positioning System remains a novelty for niche markets. The system's future hinges less on technology than on politics, economics and human nature.

Has GPS Lost Its Way?

BY CLAIRE TRISTRAM

PHOTO-ILLUSTRATION BY STEPHEN BIVER

In 1982 Charlie Trimble, a Silicon Valley entrepreneur, paid Hewlett-Packard $80,000 for the remains of a canceled engineering project—shelves full of research notes, and the result of that research: a circuit board the size of a coffee table. The circuit board could pick up a signal from the first satellite in what would eventually become the Navstar Global Positioning System (GPS), a ring of 24 military satellites orbiting 18,000 kilometers above the earth.

Trimble's company, Trimble Navigation Ltd., has since shipped GPS receivers for applications as varied as tracking wild goats in Galapagos and measuring tectonic movements atop Mount Everest. In 1991, Trimble sent $7 million worth of receivers to Gulf War GIs. Trimble's principal competitors began their careers working for him before founding their own companies. And after nearly two decades of evangelizing, Trimble still hasn't lost his enthusiasm for the technology—there's not a trace of doubt in his voice when he lauds GPS for doing everything from ending world hunger to winning the Cold War. "Knowledge of position has tremendous benefits—to feed the world, to provide more efficient commerce and therefore better quality of life, to provide better safety and security," he says.

On the other side of the country from Charlie Trimble's office, in Lowell, Mass., Charley Richardson, director of the Labor Extension Program at the University of Massachusetts, has spent just about as many years studying the effects of technology on the workplace as Trimble has developing and selling GPS receivers. Richardson recently completed a study on the effects of GPS-enabled monitoring in the transportation industry. He believes GPS can lead to gross violations of an individual's right to privacy, a problem that he believes far overshadows the technology's potential for good.

Between these two extremes lie the rest of us, most of whom haven't really thought all that much about GPS. This is, after all, a technology that has been touted for the past 20 years as being on the verge of changing the world, but which somehow never quite meets the expectations of shareholders, pundits or the press.

The idea is simple: when a GPS receiver picks up satellite signals, it calculates its position based on its distance from each satellite *(see illustration, p. 72).* A receiver needs three satellites to get a fix on its latitude and longitude; to give an extra measure of reliability, and to determine altitude as well, the unit needs to fold in a reading from a fourth satellite. A constellation of 24 satellites gives round-the-clock, global coverage.

Creating this system was an elegant feat of engineering, but the public has managed to restrain itself from buying in. In 1991, after the Gulf War victory, commercial applications like in-car navigation were expected to rocket to an $8 billion annual U.S. market; instead, people bought road maps. The domestic GPS market finally inched over $1 billion in 1997, according to Mountain View, Calif.-based market research firm Frost & Sullivan. Last August, Trimble was removed as CEO of the company he founded by his board of directors, after several quarters of disappointing sales. When it comes to the effect GPS will have on our lives, both Trimble and Richardson are speaking in the future tense.

The history of GPS is a classic case of technology in search of a market; the future of GPS will have less to do with technology than it does with politics, with economics and with simple human nature.


110°N 46°W
60°E
145° W
23°S 140°E

Tapping the Military's Assets

It's human nature, for example, to want something for nothing. The GPS network was developed for the military. Civilian usage was an afterthought. The Department of Defense (DOD) put limits on the accuracy of the civilian signal to protect national security, a practice the Air Force euphemistically calls "selective availability." The satellites were paid for and are maintained by the military as a way for missile strikes to be launched with precision on military targets, using a technology based on triangulation.

"It was developed as a military system, and never intended for commercial use," says Aaron Renenger, spokesperson for the GPS Joint Program Office at the Los Angeles Air Force Base. "It allows us to guide bombs to target within meters of accuracy, or to guide our soldiers on the ground. But in addition to the military use, we've now become stewards of a global utility for civilian applications. It's a struggle to satisfy all of the competing interests."

Commercial GPS businesses benefit directly from free use of the $17 billion in assets currently in orbit, plus an additional $500 million that DOD spends to monitor and maintain the satellites. Unlike other satellite-based industries, GPS vendors can be confident these assets will be maintained even in the event of damage from meteor showers or other acts of God. Furthermore, purchasers of GPS receivers benefit from having a free signal: There are no monthly service fees for accessing GPS.

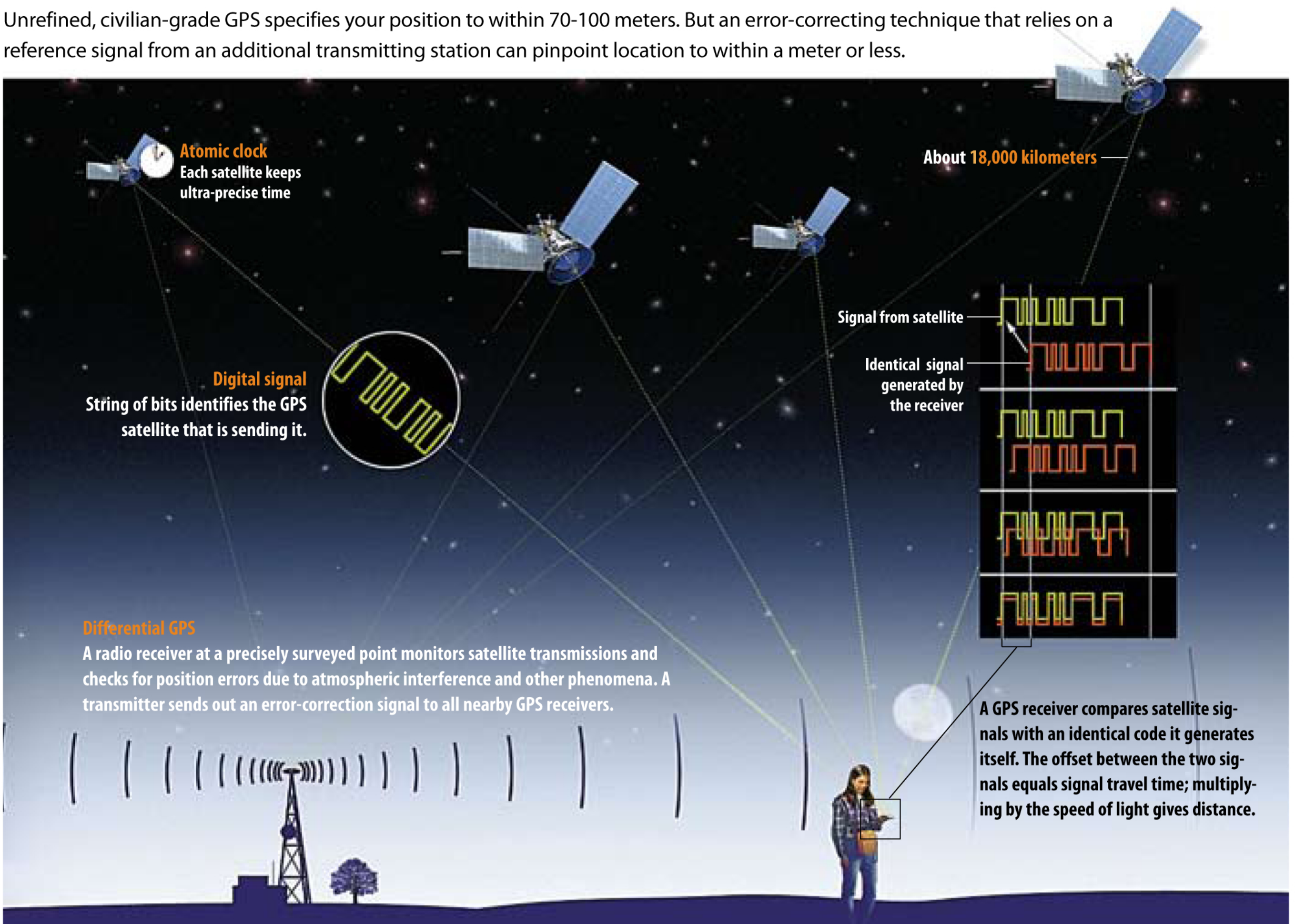
But government largesse has been a mixed blessing. Commercial GPS was almost killed by the government, along with much of the space program itself, in the 1970s. The Challenger disaster in 1986 stopped NASA dead in its tracks, and all deployment of GPS satellites was put on hold for three years. Not until 1996 did the U.S. government finally define its obligations to the commercial GPS market, when President Clinton signed the Presidential Decision Directive on GPS. This directive guaranteed for the first time that GPS signals would be permanently available to civilians, although the satellites would remain under Pentagon control.

Even with the president's assurance that GPS will remain a commercial asset, the association between GPS and the DOD creates uneasiness in the private sector—and outright animosity in some foreign governments. DOD management of GPS has driven both Russia and Europe to develop their own systems of satellite networks for location and navigation.

"There are foreign users, be they government or private, who don't want to be subject to the whims of the U.S. government in relying on this system to provide critical positioning, navigating, and timing information," says Jim White, vice president for corporate communications at Sunnyvale, Calif.-based Ashtech-Magellan Corp., a competitor of Trimble Navigation. "The French just flat out don't want to be dependent on us," says White. " A lot of other

Wherever You Go, There You Are!

Unrefined, civilian-grade GPS specifies your position to within 70-100 meters. But an error-correcting technique that relies on a reference signal from an additional transmitting station can pinpoint location to within a meter or less.



BETSY HAYES

governments feel the same way. It's an issue that won't go away."

The conflict came to a head a couple of years ago, when several member countries of the International Telecommunications Union tried to grab a chunk of the radio spectrum that GPS satellites use to beam navigation signals down to earth. Their aim was to reserve those frequencies instead for European-based mobile communications carriers. The effect would have been to interfere with GPS signals—and the resolution was less than cordial.

"The other side was so sure of victory that they were ready to put prototypes out there and actually jam the signal," says Trimble. "They locked up votes in blocks from Europe and Asia and took us completely by surprise. They had 47 votes, including Britain, Germany, France, Italy, Spain, Japan, Korea, Australia, New Zealand, Brazil and Mexico. We had six." This threatened encroachment of the GPS spectrum was averted, says Trimble, only when NATO high commander Wesley Clark intervened. Clark "called 10 Downing Street and said 'Look, we're carrying your water in Iraq and Bosnia. Stop messing around with us.'"

Locating a Market

Having access to $17 billion in capital equipment has also led the commercial GPS industry to develop technology solutions well before the market asked for them, at price points too high for the demand. GPS was a natural enabler for ocean navigation, where Trimble Navigation made its first mark, and for desert warfare, where flat horizons permit access to up to 12 satellite readings at once. Beyond these applications, handheld GPS receivers for consumer use have been niche-marketed to death—for golfers to measure their drives, for hikers to find the trail, and for the devout to find the precise direction to Mecca. Receivers have replaced Mont Blanc pens as the corporate novelty gift of choice. But this splintered market has not led to a robust industry. "The problem with this stuff is how to make money from it," says Tom Starnes, director of embedded microcomponents at Dataquest, a market-research firm in San Jose, Calif. "Just because a technology is feasible doesn't mean I'm going to pull my wallet out and buy it."

The signal provided by the DOD network has also proven to be too inaccurate for many commercial applications. Even without the intentional degradation of the signal that civilian users must suffer, the basic GPS network only provides accuracy to within seven to 10 meters. That's sufficient if your aim is to bomb a military installation, but totally inadequate if you're trying to locate a fire hydrant hidden in a field of weeds. And the signal that civilians receive can reliably tell your position only to within 70 to 100 meters. Hikers have died in Alaskan snowstorms, so trusting of their handheld GPS receiver that they continued to search for the shelter they knew was agonizingly near, instead of digging in and saving themselves. Others have walked off precipices in Scotland in the fog.

A technical solution known as differential GPS uses an earth-based receiver/transmitter at a previously surveyed point, which can receive the satellite signals, compare the GPS-determined location with the actual location, calculate the error, and broadcast corrections to handheld receivers in the vicinity. In 1994, Ashtech implemented such a system for the Coast Guard, providing accuracy to within a few meters along the entire coastline of the continental United States, sections of the Mississippi River basin, the Great Lakes region, Puerto Rico, and portions of Alaska and Hawaii. Trimble Navigation, Ashtech and a third company, Novatel, also market differential GPS packages including portable transmitters that can be placed over a surveyed site, providing location information with a margin of error measured in millimeters.

"In the commercial market, accuracy is addictive," says Trimble. "To get to the level of accuracy people demand, you need differential techniques. Selective availability really isn't a factor anymore, since even without it the accuracy would not be precise enough. It's a completely different problem from the one we were trying to solve when we began the company."

After 20 years of battling government interference and disappointing growth, two developments are finally giving the commercial GPS industry reason to hope. The first is the sinking price of GPS-enabled chip sets, which are following Moore's Law with a vengeance and will soon be available for about $10. With basic hardware that cheap, it becomes economical to embed GPS in cell phones, pagers and dashboards, without significantly raising the price of these items. "What held up market adoption had nothing to do with GPS," says Dave Nelson, director of GPS programs at the Aerospace Corp., an organization that works with the Air Force to maintain and develop GPS satellites and ground-based support. "It has more to do with getting the cost down so any consumer wants it, instead of just being something attractive to gadget freaks."

The second development in GPS's favor is the rise of complementary technologies such as digital mapping and wireless communication. Digital mapping translates GPS's latitude and longitude readings into something useful. For many of us that means dashboard displays that show where we are and how to get where we're going. For farmers, the combination of GPS and geographical information systems helps pinpoint the yield effects of fertilizer application down to the square meter, thus lowering fertilizer use, reducing pollution from runoff, and increasing yields. And com-

GPS's "Week 1K" Problem

Everyone knows about the calamity that may befall the world on January 1 because of the Y2K computer bug. Hints of what may come could appear in the Global Positioning System (GPS) more than four months before the turn of the millennium owing to an analogous quirk in GPS's unique timekeeping system.

GPS satellites communicate time through a 29-bit binary number, of which 10 bits are allocated to a "week number." For GPS, time began on January 6, 1980; on August 22, 1999, the week number will reach 1,024. Since this number is too large to be represented by a 10-bit sequence, the week number will roll over to 0. GPS receivers that aren't programmed to deal with this will think it's 1980 rather than 1999. Since GPS calculates position based on timing signals, this glitch could throw off navigation calculations.

The Defense Department's Joint Program Office for the GPS system asserts that GPS satellites, their control systems on the ground and military GPS receivers will handle the rollover correctly. Some civilian receivers, however—particularly older ones—may think they've been transported back to the time of Rubik and Reagan and lead their users astray. Major GPS manufacturers are providing information on their Web sites about which models correctly interpret the week number rollover, and are offering free upgrades to units that are out of compliance. **—Jeff Foust**

munication networks in combination with GPS allow for a new range of applications, from tracking fleets of taxis to locating your lost child in the mall by paging her. The first widely adopted communication-based application for GPS will likely be a national emergency service that pinpoints the location of cellular phones calling 911, mandated by the Federal Communications Commission to be in place by 2001.

It's the communication-based GPS applications that really energize Trimble. “The most exciting application of GPS in my mind has to do with the guidance and control of mobile platforms,” he says. “To get to there, we need to integrate with allied technologies. What's truly valuable isn't GPS, it's knowledge of position. GPS is just a fundamental way to get there.”

The value of such GPS systems are clear, agrees Ron Stearns, an analyst for research firm Frost & Sullivan who has studied the GPS market. Stearns argues that “the benefits are very easy to see in the area of emergency response, where you can better direct available emergency response vehicles to a location.” Indeed, according to Stearns, communications-driven applications will fuel the GPS market, which Frost & Sullivan predicts will grow at a steady 20 percent over the next few years.

The technology that **makes it easy to** manage truck fleets can **also be used to** monitor human activity.

But when you start to link GPS with communications networks that monitor movements remotely, some folks get nervous. The same technological infrastructure that makes it so easy to manage physical assets, like truck fleets and boxcars, can also be used to monitor human activity. Is this an intrusion society is willing to invite? The idea of “being watched all the time” bothers the University of Massachusetts' Richardson.

Remoteness Disappears

THE FIRST TO FEEL THE EFFECTS ARE THOSE WHOSE WORK has traditionally brought them far from the eyes of supervisors. With GPS, that remoteness disappears. Says Richardson: “A direct effect of GPS monitoring is that you can identify any place where there might be slack in the system. If a shipper has a loading dock that backs up, he can divert trucks to another dock. What that means for the trucker is that a natural break in his work is being taken out. His control over the day is taken away, and there is an intensification of the work day as a result of the technology.”

Differences of opinion like these led to the 1997 strike at United Parcel Service. An early adopter of many information technologies, the company thought GPS would be an efficient way to keep track of its fleet from a central location. In 1996, UPS began equipping its trucks with GPS receivers that could be monitored from a central location. Employees thought poorly of the idea. The current contract between UPS and the International Brotherhood of Teamsters forbids GPS to be used continuously, or for evaluating employee performance.

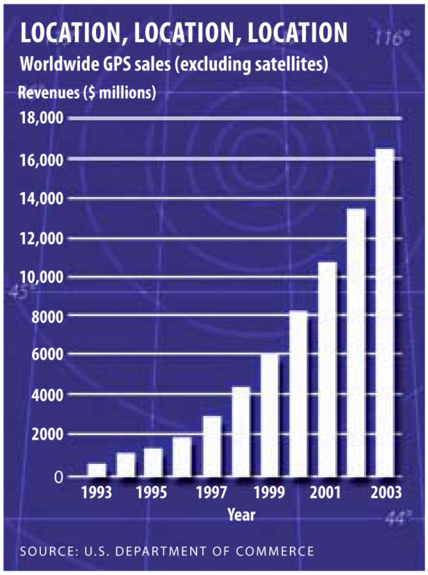
“We weren't at all opposed to the technology, as long as it helped our workers to do their jobs better,” says Paul Boldin, research director for the Teamsters. “GPS is useful as a way to optimize routes, but for that purpose it doesn't need to be done continuously. Guys at UPS are working their butts off, running from stop to stop. They don't need the additional hassle of being tracked. If the work is not getting done, it's going to show up in late deliveries and poor customer feedback. GPS in that case is overkill.”

When we use the Internet these days we don't think much about the technology's origins as a defense communications network. GPS however is still, at its heart, an enabling technology for war. Though the system now in place represents the combined effort of public and private innovation, national security is its bedrock mission.

Still, encouraging changes are on the way. In 1996 President Clinton ordered the U.S. military to cease its policy of intentionally degrading civilian GPS signals by no later than 2006. The Pentagon will, however, retain its capacity to degrade the signal for purposes of national security in specific regions. During a future war in the Balkans, for instance, the U.S. military will be able to distort the location information just in that region, while leaving other parts of the world unaffected.

The consumer market will see other improvements as a new array of 24 satellites is deployed. The new models—scheduled for launch between 2003 and 2010—will transmit civilian location signals at not one frequency but two. This additional frequency will allow the GPS receiver to detect and then compensate for distortion of the GPS signals as they pass through the atmosphere. (The military will continue to operate its own separate GPS frequency, to which civilian receivers will not have access.) Meanwhile, improvements in algorithms will eventually allow GPS to be used even in urban canyons and dense foliage, areas where it's currently weak. Startup companies such as SnapTrack in San Jose, Calif., are already marketing their GPS devices specifically for use in city centers.

Even with such gains, it is by no means a foregone conclusion that GPS will become a ubiquitous utility. Evidence to date suggests that phenomenally accurate location data are of interest mainly to specialized niche markets. Enthusiasts like Charlie Trimble argue that the falling price of the hardware will lead to a new era of location-awareness, with GPS receivers embedded in scores of everyday objects much the way clocks are now. But is this information valuable? Is it useful to the average consumer? Those are the kinds of questions that will determine the future of GPS, a system that has been “on the horizon” for a long time now and doesn't yet have a clear route home. ◊



BETSY HAYES

That's Not How My Brain Works...

Jeff Hawkins, creator of the PalmPilot, has other, much larger ambitions. He wants to figure out how the brain does its thing. Technology is just a byproduct.

Q & A

The PalmPilot is arguably the most successful new computing product since the introduction of the original IBM PC in 1981. A pocket-sized device that can read handwritten commands and interact with personal computers, the Pilot was introduced in 1996; by the end of this year, Palm Computing will have sold more than 3 million Pilots, in the process making its inventor, Jeff Hawkins, a rich man.

In some ways, Hawkins and the Pilot are a typical Silicon Valley story—years of hardscrabble technical work followed by a sudden leap into the financial stratosphere. Indeed, Hawkins soon did what successful computer pioneers often do: he left Palm in 1998 to create another new company. The secretive enterprise, called Handspring, has said only that it plans next year to introduce new hardware products based on Pilot software.

In other ways, though, Hawkins' story is different. Soon after graduating from Cornell's engineering school in 1982, he landed at Grid Systems, one of the first companies to make laptop computers. But all the while he was falling under the spell of another, wholly different field: neuroscience. His fascination grew so intense that in 1985 he abruptly left Grid and enrolled at the University of California at Berkeley as a graduate student in the field. Two years later, he returned to Grid with equal abruptness—but carried with him some ideas from neuroscience that he thought could have a big impact in the computer world. Indeed, the PalmPilot, which recognizes patterns written by a pen or stylus, is a direct spinoff from Hawkins' work in theoretical neuroscience. Grid's corporate parent, Tandy, became one of the original investors in Palm, which is now owned by 3Com.

Charles C. Mann, a frequent contributor to *TR*, started his interview with Hawkins by asking why he quit graduate school.

HAWKINS: I hated academia. I just couldn't take the culture. I would make appointments with professors and they wouldn't show up—and wouldn't even apologize. So I went back into business.

TR: What triggered your decision?

HAWKINS: I wrote a PhD thesis proposal to the chairman of the graduate group in neurobiology. He said, "This is great. But there's nobody at Berkeley who is doing this work, and you have to work for a professor, so you can't do it." He recommended spending four years getting my doctorate in neurobiology, doing research in a related but different area. And then maybe as a postdoc, I could work on what I wanted to. But I had left my job to pursue specific ideas I had about intelligence and neurobiology, not to pursue someone else's research.

TR: Why didn't you study this when you were young, and it would have been OK to be a grad student?

HAWKINS: I grew up in a family of engineers. My father is an engineer, my brothers are engineers. I was a happy-go-lucky kid who just went with the flow. In my family,

PHOTOGRAPHS BY ANNE HAMERSKY

Autoassociative memories will be a very large business, says Hawkins. Someday, more silicon will be consumed building such devices than for any other purpose.

that meant becoming an engineer.

TR: It doesn't sound like your heart was in computers. But you still went back to them after quitting Berkeley.
HAWKINS: I asked myself what I should do with my understanding of neurobiology and intelligence. I decided that I would go back to work and hopefully achieve some wealth and notoriety from my computer work. I would then use those resources to promote my ideas about neural function in a scientific and popular fashion. I created Palm Computing and Handspring primarily so that in the not-too-distant future I will be in a position to develop and promote my ideas about intelligence and how certain parts of the brain work.

TR: So you're not at Handspring to be in business?
HAWKINS: I love handheld computers and I love building businesses, but those are not the main reasons I do what I do. I plan to use the money that I am making to fund research on the human brain.

TR: What do you want to add to the tremendous amount of neuroscience research that's already being done?
HAWKINS: In reading about the brain, I found that what was conspicuously absent was any sort of overarching theory to explain it. I noticed brain research was paying little attention to certain things. For instance, look at the cerebral cortex, or neocortex. It's essentially a big sheet of neurons several millimeters thick. Although there are areas dedicated to vision, speech, touch and motor output, it's a remarkably uniform structure—the areas that deal with vision are almost identical to those dealing with hearing. This similarity implies that the same basic mechanism underlies all sensory processing. This is a remarkable finding—yet it has been generally ignored.

TR: Why is this discovery so important?
HAWKINS: Because it helps explain how the brain processes all the information it receives. The major inputs to the brain are the optic nerve, the spinal cord—touch, if you will—and the auditory nerve. However, there's really only one thing coming into the brain: patterns of neural firings. Now think about what these neural patterns are really like. First, your eyes are moving all the time. While you're looking at my face, your eyes are doing these little dance movements called saccades. Combine this with the fact that a large portion of the fibers coming in at the optic nerve represent a small central portion of the visual field—the fovea. With every eye movement, the neural pattern in the optic nerve changes. This means that vision is not just a problem of spatial pattern recognition, but of time-based patterns. The temporal nature of vision has been ignored by almost all theories dealing with vision. The key to understanding vision is to understand the importance of the time-varying patterns. By the way, hearing and touch work in the same way as well.

TR: Hearing seems clearly related to time-based patterns. But touch?
HAWKINS: Sure—the role of the fovea is played by your fingertips and the role of the saccade is played by the movement of your fingers over an object. Feeling an object creates a time-varying pattern. As the neocortex suggests, a common mechanism underlies vision, touch and hearing.

TR: How does this fit in with your model of the brain?
HAWKINS: You have to consider it together with the dominant nature of feedback. People tend to view the brain as a sort of input-output box. The input comes in, it gets processed, and out pops the result and you do the right thing. Well, if you look at the interconnections in the brain, there are many more fibers feeding backward than feeding forward. There's more information traveling toward the input areas than there is toward the output areas—the ratio can be as high as 10 to 1. This is again something that is well known, but generally ignored because people don't know what to make of it.

TR: OK—what should we make of it?
HAWKINS: One of the biggest implications is that parts of the brain look like what are called autoassociative memories. This is a type of memory that was partially inspired by neural architectures. It means that you provide part of what you're looking for and you get the rest of it back. Clearly, that's something brains are good at—memory is aided to a huge extent by context. You're given a clue to something—say a taste or smell or image—and then you follow this progression of autoassociative recall.

TR: And you see this as leading to a theoretical model of how the brain functions?
HAWKINS: Yes, but there are problems. People who have studied the mathematics of autoassociative memory structures have found that if you make big autoassociative memories, they can't store enough data. That is, if I make the memory 10 times larger, I can't put 10 times as many data items in it. I can put *bigger* data items in it, but I can't put *more* data items in it. So people have struggled with autoassociative memories as a model for brain function, because they have too limited a capacity.

TR: So why do you want to go back to them?
HAWKINS: Because I had a different approach. The earlier studies had been trying to apply autoassociative memory only to spatial data. But if you apply autoassociative memories to time-based data, you might be able to overcome their limitations. Remember, when you have bigger and bigger autoassociative memories, you can't store more items—but you *can* store bigger items. If I view those bigger items as time-based data constructs, then I may not know a tremendous number of things, but I know a tremendous number of temporally connected things.

TR: What does all this have to do with intelligence?
HAWKINS: It goes back to my view that the brain is not just an input-output box. I think that intelligence is an ability of the organism to make successful predictions about its input. Intelligence is an internal measure of sensory prediction, not an external measure of behavior. When you look at my face, your eyes don't just go randomly around. They look at very specific things. Typically they will look from

eye to eye to nose to mouth. What your brain is doing during this process is saying, essentially: I see a pattern here that might be a face, and this might be an eye. And if I see an eye here, there should be another eye over there. It's expecting a certain neural firing pattern at that instant. If you were to look at a face, and see a nose where an eye should be, then you'd know immediately something was amiss.

TR: So we have fundamental assumptions about things that help us make sense of the world.
HAWKINS: Say I moved the doorknob on your front door up an inch. Now when you come home, you'd reach out for the doorknob, and it wouldn't be in the right spot. You'd notice that immediately, a misprediction. What if I made the doorknob a little wider or narrower? What if I made it stickier or heavier? I can think of a thousand changes I could make to your door and you'd notice them all. Now, the approach to this in traditional artificial intelligence (AI) research is to create a door database or door schema—a compilation of all the door's properties. Then the AI machine would test every one of those properties, one after another.

TR: And you're saying this is not how real brains work?
HAWKINS: I can guarantee you that. Your brain has no door database. We have to have a mechanism that tests all these door attributes at once. Autoassociative memories naturally make predictions about all their inputs. They are a great candidate mechanism. In a nutshell, intelligence is the ability of a system to make these low-level predictions about its input patterns. The more complex patterns you can predict over a longer time, the more you understand your environment and the more intelligent you are.

TR: How did these ideas lead to the PalmPilot?
HAWKINS: I was at Berkeley in the mid-1980s, which was just when neural networks were becoming fashionable again. A company called Nestor was trying to sell a neural-network pattern analyzer to do handwriting recognition—for $1 million. I thought, there have got to be easier, better ways of doing this. I took some of the math I was working on and designed a pattern classifier, which I received a patent on.

TR: What did you do with it?
HAWKINS: Just for fun, I built a hand-printed-character recognizer. Then I thought about building a computer that could use it. This started me down the path of building pen-based computers, first the GridPad and eventually the PalmPilot. The pattern recognizer in today's Palm products is based on the same recognition engine I created 12 years ago. It was inspired by the work I was doing in autoassociative memory.

TR: So the PalmPilot was just a byproduct, not a goal.
HAWKINS: Yes. I figured I could be successful building little computers that used my recognizer. It would give me some time to think about how I would get other people interested in autoassociative memories. Originally, I thought I would build portable computers for four or five years, make a name for myself, and then work full time on neurobiology.

TR: It has been almost 15 years.
HAWKINS: Yes, but that's still my intent. In the next couple of years I hope to start spending more time on autoassociative memories. If I get to my deathbed and I haven't made a significant contribution to the theory of how the brain works, I'll be disappointed.

TR: Meanwhile, might your ideas about brain function lead to other commercial possibilities?
HAWKINS: I wouldn't be surprised. One way to progress a science very rapidly is to find a commercial application for it. There is nothing like commercial success to get more people working on a problem.

TR: What sort of products do you imagine?
HAWKINS: Building autoassociative memories will be a very large business—some day more silicon will be consumed building such devices than for any other purpose. The amount of storage in a human brain is extremely large. It is impractical to use current memory technology to build memories anywhere near this capacity. Fortunately autoassociative memories are fundamentally different than the kinds of memories we put in computers. When you build memory chips, their capacity is limited by the physical size of the die. Since silicon will have a certain number of defects per square millimeter, if you start making the chips too big, you'll get a lot of chips with defects. Eventually the yield of good devices becomes unacceptably low—you have to throw away too many chips, driving the cost up.

TR: But this won't be true with autoassociative memories?
HAWKINS: Right—they are naturally fault-tolerant. If some percentage of the cells don't work properly, it doesn't really matter. Autoassociative memory chips will be very large and relatively cheap.

TR: What would they be used for?
HAWKINS: This is a little like asking in 1948 what the transistor would be used for. I believe autoassociative memories, like transistors, will be an enabling technology. The early applications will be modest. Ask what problems can benefit from a system that understands its environment, can predict what ought to be happening next and can recognize unexpected and undesirable events. Any human job that requires lots of attention to patterns and few motor skills is a candidate. Security surveillance could be an interesting market to start with.

TR: There are a lot of applications like that.
HAWKINS: How you get there in five steps, I really don't know. What drives me is my absolute certainty that this is the right approach to how brains are built. ◊

Care for Steak TATA?

IT SEEMS LIKE ONLY YESTERDAY THAT ALFRED Vellucci, the crusty mayor of Cambridge, Mass. during the 1970s and self-styled one-man poison pill to the burgeoning biotech industry, hauled the cloners of Harvard and MIT before the city council and gave them a lesson in English 101. "Most of us in this room, including myself, are lay people," he solemnly intoned during an infamous June 1976 meeting, during which the burghers debated a moratorium on experiments using recombinant DNA. "We don't understand your alphabet. So you will spell it out for us so we'll know exactly what you're talking about..."

A scientist stripped of jargon, it must be said, offers a particularly forlorn form of public nakedness. Although I never found Vellucci's scientific arguments against recombinant DNA very convincing, I have always had a grudging admiration for the populist economy with which he revised the terms of the debate. He displayed an artful ability to see that a common vocabulary was essential to resolving (or, in this case, roiling) public debate about a new technology.

"Can you make an absolute, 100 percent guarantee that there is no possible risk which might arise from this experimentation?" Vellucci asked at one point. No one could, of course. By keeping things simple—in many cases, too simple—certain words and terms assumed an aura of dread.

I thought of Vellucci and the power of simple words to shape public perceptions because of a recent news report out of Tokyo. At least 66 head of "cloned" cattle, and perhaps many more, had inadvertently been sold to Japanese consumers, unleashing fears about the the safety of bioengineered beef. Steak TATA, anyone?

There are several reasons to suspect those fears were exaggerated, starting with the fact that it is a common practice among livestock breeders to split embryos during in vitro fertilization—that is, create identical twins, or "clones"—in order to get two or more prized animals for the price of one fertilization. Moreover, the Japanese cattle apparently did not have any genes added, deleted or manipulated.

The real interest, to my mind, is the way the word "clone" continues to set society's hair on end. Biologists have for decades been notoriously promiscuous in their use of the technical word "clone"; it can mean anything from a replicated piece of DNA to Dolly, from an identical brood of frogs to a Frankensteinian (and, to date, still hypothetical) human experiment. Outside the scientific community, the word has acquired a meaning altogether different—something eerie and unnatural—that may forever pose significant problems for the biotech industry.

The word "clone" has acquired an eerie, unnatural meaning that may forever pose problems for the biotech industry.

Mere words, taken out of their customary context, become shorthand for social anxieties. Consider the legacy of "nuclear magnetic resonance." As long as researchers applied the technique to a lowly clam, as in the earliest experiments, no one had a problem with what is, after all, a perfectly descriptive technical phrase. Start sending humans into machines for diagnosis, however, and suddenly "nuclear magnetic resonance" starts to sound like the kind of medicine they practice at the Three Mile Island HMO. Hence, "magnetic resonance imaging."

In this age of linguistic deflation, where innocent bombing victims become "collateral damage" and sex is not legally "sex," perhaps the most underappreciated sector of the economy is the booming business devoted to the manufacture of catchy metaphors and euphemisms. Biotech and its discontents have battled for decades over clones and "suicide" genes and, more recently, "Frankenfood."

There are two ways to look at these debates. One is that the uproar over cloned Japanese beef is merely the latest in a long line of examples in which the human frailty in risk assessment is richly and abundantly on display. Of all the possibilities to fear when buying a piece of meat—contamination with a toxic strain of *E. coli,* dietary cholesterol, hormone residues, even the car ride home from the store—the fact that the beef was "cloned" seems trivial in comparison.

But there is another, less dismissive way to view the Japanese controversy. It may well be that the vague but widespread public unease about the genetic future of our food supply *(see "Biotech Goes Wild," p. 36)* gathers itself around a suggestive word or phrase. The specific fear of "cloned" beef may be silly, but the general discomfort level about bioengineered food is legitimate and, I suspect, not transient. Whether the phrase appears on a textbook or a food label, "genetically engineered" continues to have a sinister connotation, which is why agribusiness has worked so mightily to keep those words off packaging.

Most scientists consider Alfred Vellucci's objections to cloning unscientific and misinformed. But another Cambridge city official, David Clem, put his finger on a problem that will never go away when societies grapple with new technologies. "I tried to understand the science, but I decided I couldn't make a legitimate assessment of the risk," said the former city councilman. "When I realized I couldn't decide...on scientific grounds, I shifted to the political." And in politics, the definition of every word is up for grabs. ◊

TR100

Special Issue... Coming in November

The Top 100 Young Innovators

Our TR100 Judges and their thoughts on innovation...

Think of something new, you've got an invention. Change the world in which we live, you've got an innovation.

Arno Penzias
Venture Partner, New Enterprise Associates
Nobel Laureate-Physics 1978

I think if you really believe in yourself, if you really stick to what you're doing, there is very little that is impossible.

Robert Langer
Kenneth J. Germeshausen Professor of Chemical and Biomedical Engineering, Harvard-MIT Division of Health Science and Technology

Inventing can be tricky, but selling, now that's a really complicated part of innovation.

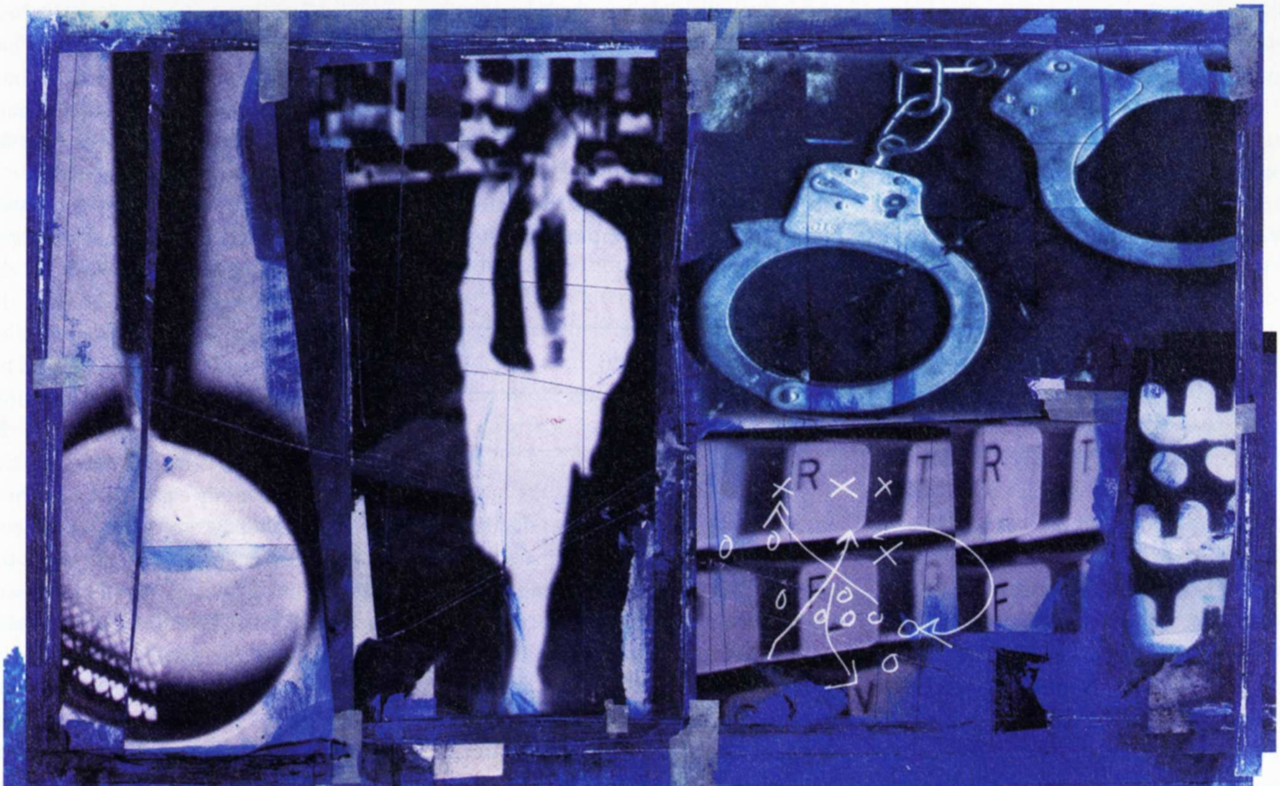
Bob Metcalfe
Technology Pundit; Vice President, Technology, International Data Group; Inventor, Ethernet; Founder, 3Com

A couple decades ago there were just a few real risk takers — the true pioneers of this amazing industry.

Ann Winblad
Partner/Co-Founder, Hummer Winblad Venture Partners

Panel of Judges:
David Baltimore
John Benditt
Al Berkeley
Anita Borg
Morris Chang
Michael Dertouzos
John Doerr
Bruce Journey
Ellen Knapp
Robert Langer
Bob Metcalfe
Nicholas Negroponte
Arno Penzias
Kim Polese
Diana Garcia-Prichard
Judith Rodin
Phil Sharp
Alan Spoon
Ray Stata
Anthony Sun
Chuck Vest
Larry Weber
Ann Winblad
Wm. A. Wulf
John Yochelson

MIT'S MAGAZINE OF INNOVATION
TECHNOLOGY REVIEW



ANASTASIA VASILAKIS

VIEWPOINT | BY SIMSON L. GARFINKEL

The Documents in the Case

In cybercrime, they're printouts—and not to be trusted

THE LETTER FROM CARL PAYNE CAME in the spring of 1998. It was handwritten—no letterhead. I was suspicious. Being a columnist for *The Boston Globe* and the author of seven books, I get my share of communications from cranks, crazies and convicts. But Payne, I soon realized, was none of the above.

Payne wrote that he was the defendant in a criminal computer-hacking case. Back in December 1994, at the age of 28, he had helped start an Internet service provider in Utah that was eventually named Fibernet. But in the autumn of 1996 the board voted to oust Payne after he locked horns with the man who was poised to become Fibernet's new president.

A week after Payne left Fibernet, someone had hacked into the company's computers and ransacked their systems. Fibernet had immediately fingered Payne and persuaded the Utah County Attorney's office to charge him with violating Section 76-6-703 of the Utah Criminal Code, "Computer Crimes," a second-degree felony. The prosecution had a pile of evidence, the case was going to trial, and he needed my help.

At first glance, Payne did indeed look like the likely culprit. Studies have shown that most computer crimes are perpetrated by disgruntled employees. Most computer-hacking cases that reach a courtroom pivot on some aspect of the law, such as whether the hack was illegal—and not on whether the suspect actually did it. I had never heard of a case in which the accused "hacker" maintained his innocence, especially in the light of hard evidence. Yet that's just what Payne was doing. Intrigued, I called him.

On the telephone Payne was talkative, friendly—and very worried. We agreed that he would send me all the evidence the County Attorney's office had provided to his lawyer. I would assess its quality and write a report. If the case went to trial, and he still wanted me, I would come to Utah and testify. It would be my first stint as a paid expert witness.

A week passed and a thick packet

arrived in my mailbox. It contained Payne's account of the incident, the police report, depositions from all involved, and nearly 200 pages of computer printouts. After four hours spent poring over the documents, I emerged into the living room and told my wife: "Things don't look good for Mr. Payne."

Payne's last day of work was October 30, 1996. On November 6, someone had logged into each of Fibernet's main computers and started deleting files. Customer Web pages and e-mail were erased. Accounting information was wiped out. Then the attacker gained access to each of the company's special-purpose communications computers, called routers, and deleted their programming. Ultimately, the company lost more than half its customers, laid off many employees, left its managers without salary, and nearly folded.

Payne, who had been Fibernet's chief technical officer, certainly had the knowledge necessary to pull off the assault. And after his messy departure, he might have had a motive: revenge. Some other details also seemed to point in Payne's direction: Among the several accounts utilized in the hack was one called "carl," which presumably belonged to him, an account called "dbowling," which belonged to one of his friends, and one called "usenet." Sometime prior to the attack, somebody had modified the "usenet" account and given it full system privileges, creating—to use the lingo of computer security—a "back door."

But perhaps the most damning document in the package was the report of the police officer who had gone to Payne's house following the attack. When the officer arrived, he found that Payne had reformatted his home computer's hard drive and was reinstalling the operating system. In the trash can next to the computer was a pile of floppy disks. The officer neither impounded Payne's computer nor seized the floppies—he later testified in court that he had assumed any potentially useful evidence was already destroyed.

It all looked suspicious. But another call to Payne produced a different perspective. The last week he was at Fibernet, Payne told me, he had turned over all the company's administrative passwords to the new president. The next day, Payne discovered that his password had been changed. On the morning of the attack, Payne said, he had tried dialing Fibernet on his modem several times, on the remote chance that his account had been somehow re-enabled, but he had never successfully logged in. In fact, he was reformatting his home computer because it crashed every time Fibernet rejected his password. All those disks in the trash, he said, were old files he was getting rid of in preparation for a move to California.

> The printouts formed the heart of the case against Payne, but they convinced me that nobody should be convicted of this crime.

I wasn't sure whom I should believe, but I was starting to like Carl Payne. He could have been me 10 years ago—a technically savvy geek who had gotten himself in trouble with a bunch of suits who were more comfortable with spreadsheets than C compilers. Perhaps he did it, perhaps he didn't. But a closer inspection of the computer printouts that made up the heart of the prosecution's case convinced me that, no matter who the culprit was, there wasn't enough evidence to convict anybody.

For one thing, none of the printouts allowed me to pinpoint a phone number or computer from which the attack had been launched, let alone the identity of the perpetrator. And something else called the evidence into even greater question: It appeared somebody had tampered with some of the files before printing them out. The log had small typographical errors—a few extra spaces inserted on one line, a letter dropped on another—as if somebody had taken the original log files into a word processor and cut and pasted text before printing. This meant that the information on those pages was suspect. And why did all of this evidence come to me in printed form? Where were the original electronic records? Guilty or not, I thought, no one should be convicted on the basis of tampered evidence.

I sent a six-page report to Payne, and continued to follow the case. In December, I boarded a plane for Utah. When I arrived at the Utah County Courthouse in Provo, the opening arguments had just concluded. The prosecution's theory was simple: Carl Payne was a technically brilliant but hard-to-handle employee. When Fibernet gave him notice that he was going to be terminated, Payne installed a back door that would allow him to wipe out the company's computers after he left.

It turned out that in ousting Payne, Fibernet had fired the only employee capable of repairing the damage from the attack. So in addition to calling the police after the incident, they had called a computer consultant to come in and try to get the system back up and running. The consultant, Stacey Son, became the lead expert witness for the prosecution.

Son's testimony explained why there were only 200 pages of printouts in evidence—Fibernet had hired him to get the system working quickly, not to document the damage for an investigation, so he hadn't attempted to preserve potentially incriminating or exonerating files. Neither had the police, it turned out: The officer who visited Fibernet and then searched Payne's house testified that he had no experience with the UNIX operating system that Fibernet and Payne used. Instead of impounding computers and disks, the officer had simply accepted the paper printouts Fibernet had handed over.

On the stand, Son admitted that there was no way for him to tell the identity of the perpetrator. But the biggest hole in the prosecution's theory became apparent when the defense questioned Son about the attack itself. It was poorly done, Son explained: Not enough information was wiped out. It seemed to me to be the work of an amateur with only rudimentary knowledge of UNIX systems, not that of somebody of Payne's admitted prowess.

The prosecution rested on Thursday, the third day of the trial. That night in my hotel room, I looked again over those critical printouts. The prosecution's most important exhibits were pages 151 and 152, which showed each account's name, user-identification number, group number, encrypted password, and a third number for accounting purposes. The user-identification number had been the subject of much testimony, since its manipulation was a critical step in creat-

ing the back door. Nobody had discussed the significance of the accounting number.

Friday morning I woke up in my hotel room at 5 a.m. I had a hunch about the elusive last number. I needed to check the documentation for the version of UNIX that Fibernet had been using. I didn't have the manual with me, but I booted up my laptop and found it on the Internet; it explained that the number was used to warn people when it was time to change their passwords—it indicated the number of days between January 1, 1970, and the last time the password was changed.

I felt stupid. Here was possibly the most important piece of evidence in the entire trial, and I had not even realized it until the morning I was supposed to testify! Encoded in the record of each account's password was the date the password had last been changed—by decoding the number, I could establish precisely when the "back door" was created. In the hours before the trial, I wrote a small program to translate the numbers.

What my homemade program showed me clinched the case. The back door had been installed on October 31st, the day after Payne's last day of work—and after his access to the Fibernet system had already been cut off. Payne couldn't have created it. What's more, another account's password change dated to more than two weeks *after* the attack, a detail that would be impossible if the printout was really the same one Son had made that day. This showed irrefutably that the chain of evidence had been broken.

At 10 a.m. I took the stand. I described my credentials, the proper handling of security incidents, the paucity of evidence, and the telltale indications that the printouts had been altered. Finally, I testified about what I had learned that morning. From that point, everything moved quickly. Payne and his wife testified, the attorneys gave closing arguments, and the jury began deliberations around dinnertime. In the late evening, they came back with the only verdict I thought they could reasonably reach: not guilty on all counts.

Today, Carl Payne oversees a large computer network in California. Fibernet, meanwhile, is thriving. In the course of the trial I came to believe in Payne's innocence, but never felt that I had learned the real story. In closing arguments, the defense suggested a few possibilities: Somebody at Fibernet could have carried out the attack. An employee whom Payne fired in July of 1996 might have done it. Or perhaps the crime was committed by some unknown hacker on the Internet, an unfortunate coincidence with Payne's dismissal.

Fibernet, for its part, declined to comment for this article.

There's really no way to know what happened, because the Utah police did not do a meaningful investigation. They simply asked the victim, "Who did it?" and Fibernet answered: "Carl Payne." The company then provided all of the evidence used in the prosecution. The police never would have followed such haphazard procedures in the wake of a physical break-in—they would have done their own detective work, carefully collecting and preserving the evidence. As more and more crimes occur in the neighborhood we call "cyberspace," police need better tools and training. Without it, we risk bungled investigations and the very real possibility that innocent people will be found guilty for the hacks of others. TR

MIXED MEDIA

Picture Imperfect

CD-ROMs are an ideal vehicle for documentary photography, but early examples don't exploit the medium's potential

NEW TECHNOLOGIES OFTEN breathe new life into older forms. In this tradition, the CD-ROM presents itself as a welcome successor to the book as a vehicle for works of photographic expression. The CD-ROM offers documentary photographers and photojournalists much of what they and their predecessors have demanded and hoped for since these crafts emerged in the 1920s and 1930s.

Just look at what the technology makes possible: vast storage space for data in different forms; high-quality representation of photographic imagery; ease of combining imagery with written and spoken text; design flexibility and versatility; control by the photographer over the editorial process; an inexpensive means of production affordable by the makers of the original material; self-publishing options; varied channels for distribution; the chance for the viewer/reader to interact with the material. These have been the desiderata for documentarians from W. Eugene Smith and Marion Palfi to Eugene Richards and Susan Meiselas. In spite of this promise, what little we have so far in CD-ROMs has gone no more than a half-step past the book as a medium.

STEVE HART/A BRONX FAMILY ALBUM

The award-winning *A Bronx Family Album*: Interactivity lite?

But there is plenty of potential for future growth, and three projects constitute appropriate reference points for contemplating the future of this marriage of form and content.

■ Pedro Meyer's *Fotografio para recordar—I Photograph to Remember* (Voyager, 1991) is based on family-album photos, Meyer's own images, and his spoken reminiscences. This account of the Mexican-born Meyer's life with his German expatriate parents was the first photography-related CD-ROM to draw attention as a serious experiment in combining contemporary photographic practice in documentary with digital technology. It came out so early in the onset of this medium that many of us who received

WEB SITE

Ready, Set...Render!

WWW.IRTC.ORG

For some people, everything is a contest—even "ray tracing," which renders a scene in realistic 3-D by computer modeling of light rays as they bounce around in the virtual world. For the last few years, computer graphics craftspeople have been submitting their work to the Internet Ray Tracing Competition. A panel of judges picks the winners and displays them on this site, which has become an archive of amazing images and animations.

Each contest has a theme, such as "history," "nature," "night," or "great engineering achievements." The winning entry for one recent topic—"imaginary worlds"—depicted, in Dali-esque style, a string quartet having a picnic; the cello and viola snooze parent-like against a tree with a musical score open like a paperback book, while two violins frolic nearby. Another recent winner (theme: "history") showed the familiar image of the Hindenburg exploding, with the flames and sparks eerily reflected from the surface of the doomed German dirigible.

ERAN DINUR

Visitors to the site can not only view the images but also read brief descriptions by their creators of the tools and techniques they employed. These passages give a glimpse of the dedication, pride and frustration of the artists. Descriptions include how long the computer cranked away to render the image. Times range from a few hours to more than a day—this is not a pursuit for those seeking instant gratification. Though only judges selected by the IRTC administrators have voting privileges, anyone can look at, and comment on, the pictures. Prizes are modest (mainly software from sponsoring companies). Contestants compete for the praise of their peers, in the process building a showcase of graphics achievement. **—Herb Brody**

review copies did not yet have the ability to play the disc in our computers. Looked at now, it is a sweet, wry, melancholic family album *cum* love story with verbal captioning—little different from what one could have achieved in print by sitting Meyer down with those photos and transcribing his tape-recorded commentary.

■ *The Deaths in Newport* (Paradox Interactive, 1995), Lewis Baltz's venture into this form, also has family-album aspects: It moves between present and past to recount a sensational 1946 murder trial in Corona Del Mar, Calif., at which Baltz's father, a mortician, served as a key witness for the prosecution. The visual component mixes Baltz's own images with archival material—news stories and headlines, court documents and tabloid photographs that chronicle the case. Baltz recounts the saga in a spare, dry prose. The visual design is more intricate than in Meyer's project, with images layered and collaged. Yet the "interactive" options remain similarly minimal; here again we have what amounts to a digitized version of a conventional photo book with voiceover.

■ Steve Hart's much-celebrated *A Bronx Family Album: The Impact of AIDS* (Scalo Publishers, 1997) won him the International Center of Photography's 1998 Infinity Award for Photojournalism, and functions right now as the most high-profile of these experiments in digital form. Hart tracks the lives of a drug-ravaged, HIV-positive Puerto Rican couple living on welfare with four children between the ages of 2 and 13 in the South Bronx. You can browse the images or let them run, and jump from selected images to spoken and transcribed interview passages. Alternatively, you can listen to the full audiotaped interviews while simultaneously scrolling through the transcript. Or you can go to a screen of thumbnail portraits of the principal characters in the narrative, click on any one and get a brief synopsis of their relation to the others and their current status quo.

Of the three projects, *A Bronx Family Album* utilizes most fully the multimedia potentials of its technology. Yet it is still not hard to imagine it converted to book form. Indeed, soundtracks aside, none of these three projects achieves much that a printed book could not.

What bets are missed? To begin with, the designers of these projects don't utilize image-mapping creatively, to create links to and from various elements within an image. And, in the case of Hart's work, mostly photographed inside the family's apartment, there was no apparent effort to establish coherently the physical space that the family inhabits, or to move you through it imaginatively. These CDs neither propose nor allow any sequencing of their pictures other than a set chronological order. Hart's CD, for example, gives you no way to view on one screen a cluster of all the images of any one of the individual protagonists. None of the CDs investigate hypertextual possibilities—lacking, for example, highlighted keywords to link you to particular images. And all this material is I-talk-you-listen—no questions posed, no space for the viewer's articulated response. This is interactivity lite.

I realize that we're still in the first decade of the interactive CD-ROM, and I don't expect definitive pieces at this point. Indeed, I consider all three of these works successes on various levels; each offers numerous insights and satisfactions. But they could have done so as books or exhibitions; they don't *need* CD-ROM. The new medium's capacity for a more idiosyncratic, complex, intuitive and participatory approach to narrative structure—of the sort that's commonplace in kids' entertainment software, and that computer users of all ages today expect as a matter of course—has been almost entirely neglected.

Why, ten years on, don't we have a whole slew of exciting experiments—even provocative *failed* experiments—in documentary photography and photojournalistic CD-ROMs? When I imagine what Dorothea Lange or Margaret Bourke-

DVD / WEB SITE

"Moon": A Giant Step for Art?


BENJAMIN BRITTON

Three decades after "a small step for man," the countdown is on for an ambitious art project to offer viewers around the world a mythic digital simulation of the first human landing on the Moon.

If all goes according to schedule for Benjamin Britton, associate professor of electronic art at the University of Cincinnati, and his team of graphics and networking specialists, the project will make its debut on July 20 in the form of a limited edition DVD-ROM disc and a Web site (www.moon.uc.edu). Britton says that while one of the aims of "Moon" is to dispel conspiracy theories that the Apollo 11 landings were a hoax, his mostly historically accurate piece does take liberties. Not only will the audience be able to witness the touchdown on the lunar surface in detailed, computer-generated graphics from the point of view of astronauts Neil Armstrong and Buzz Aldrin, but participants will also be able to see the 1969 event through the eyes of Richard Nixon in the White House. "As a child," Britton explains, "I remember seeing the Moon landing on the same television screen as all these other characters." In a surreal touch, the heavenly viewpoint of the late John F. Kennedy and Marilyn Monroe are among the perspectives available.

The virtual humans in the latest demo footage from this work-in-progress are somewhat blocky three-dimensional figures requiring tremendous suspension of disbelief. Artist/academic Britton doesn't mind: "It's the 'Veil of Isis'—the idea that any representation of the truth by humans has to be imperfect. Like a classic statue of the goddess Isis in Egypt, all you can do is make the veil as thin as possible, and make it beautiful."

—Steve Ditlea

White would have done with this new medium, my mouth waters. If this technology is to revitalize photojournalism and documentary photography and entice new audiences, such investigation is imperative, and the time is surely now.

—A. D. Coleman

NET NUGGETS

Bookmarklets: Tinkerers who would no sooner use software with its default settings than eat a candy bar with its wrapper still on have a glorious new way to futz with their browsers. "Bookmarklets" are short JavaScript programs that can be saved as bookmarks. Unlike conventional bookmarks, which zap you to a particular Web address, bookmarklets modify the look or function of whatever site you happen to be visiting. This page is full of odd little tools to customize the Web experience: change the background color; highlight a phrase and search the Web for it; check a page's "freshness."
www.bookmarklets.com

Biospace: Billing itself "the global hub site for biotechnology," this site consolidates and organizes links to breaking news, investor information, industry directories and more. The design is unusually spare and easy to use, though with success, ads are becoming more obtrusive. Sign up for the GenePool to receive a daily e-mail update of biotech industry highlights.
www.biospace.com

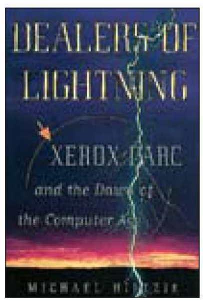
How Things Work: We glide through life on the cushion of fantastic scientific discoveries and engineering achievements that remain mysterious to a large fraction of the population. University of Virginia physics professor Louis A. Bloomfield cheerfully attacks ignorance in this question-and-answer site, serving up clear explanations of everything from from how transistors work to why balls bounce. Bloomfield created this lean (text-only) and easy-to-search page to supplement a textbook he wrote to teach physics to liberal arts students.
http://erwin.phys.virginia.edu/Education/Teaching/HowThingsWork/

PAGES | BY WADE ROUSH

Unbottled Lightning

DEALERS OF LIGHTNING: Xerox PARC and the Dawn of the Computer Age
by Michael Hiltzik
HarperBusiness, 448 pp., $26

ART AND INNOVATION: The Xerox PARC Artist-in-Residence Program
edited by Craig Harris
MIT Press, 264 pp., $35

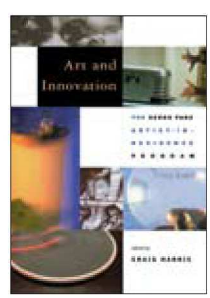


XEROX, THE DOCUMENT Company, has a natural fondness for paper. In a time when the "paperless office" is agreed to have been a comically wrongheaded vision and when paper-and-ink metaphors persist even in cyberspace (e.g., Web "pages"), that's probably good business. Xerox's loyalty to paper as a medium, however, has contributed to some notorious strategic blunders.

The biggest may have been the hostility the company showed toward the ideas coming out of its own unruly Palo Alto Research Center (PARC) in the 1970s. Between 1971 and 1979, PARC scientists invented the first truly personal computer, the first windows-based graphical user interface, the first user-friendly word processing program, the first adjustable screen and printer fonts, the computer mouse, the laser printer, and the Ethernet networking protocol to tie local computers together. These technologies make up the backbone of the modern office, yet only the laser printer was commercialized by Xerox. Company executives, blinded by their own mindsets as copier salesmen, forfeited many of the best people and prototypes at PARC to the next-generation firms that shepherded in the era of personal computing, such as Apple, Microsoft, Adobe and 3Com.

Or at least that's the popular version of the story. In his illuminating new book *Dealers of Lightning,* based on interviews with the players themselves, technology journalist Michael Hiltzik concludes that there was more to the dramatic disconnect between Xerox and Xerox PARC than simple shortsightedness. While the missed opportunities can be chalked up in part to Xerox's preoccupation with expensive copying machines, economics and a philosophical gulf between the company's East Coast executives and its West Coast longhairs had almost as much to do with it, Hiltzik shows.

One sign of this gulf was the researchers' unawareness that by allowing themselves to be featured in an anti-corporate article in *Rolling Stone* in 1972, they were in effect thumbing their noses at corporate headquarters. At the time, the visionary young scientists at PARC were hard at work on the Alto, a small personal computer that would later inspire Apple founder Steve Jobs to build the Macintosh. The article, by *Whole Earth Catalog* founder Stewart Brand, romanticized the PARC researchers as "computer bums" whose philosophy was "soft, away from hugeness and centrality, toward the small and personal, toward putting maximum computer power in the hands of every individual who wants it." In one of the book's many entertaining anecdotes, he recounts how a horrified personnel manager, upon learning of the article, asked, "What the hell is *Rolling Stone?*" "It's some druggie magazine," a secretary answered.



Xerox executives had good reason to feel beleaguered. During what Hiltzik calls the company's "lost decade," its patent on the selenium-alloy photoreceptor at the heart of its copiers expired; it faced unexpectedly strong competition in the copier market from IBM and Japanese firms; and its purchase of a moribund computer company, Scientific Data Systems, turned out to be an expensive flop. These distractions, while hardly exculpatory, have been overlooked by most previous chroniclers of how the company "fumbled the future."

Ultimately, Hiltzik's book suggests, innovation is inherently anti-establishment, and can't always be channeled for commercial gain—at least not by the organization that sponsors it.

Xerox's commitment to hard copy has recently resulted in another, albeit minor, misapprehension. This is the idea that documentation is always good and that paper can be an effective medium for any message. *Art and Innovation,* a disappointing collection of essays, jottings and transcripts by participants in the Xerox PARC Artist-In-Residence (PAIR) Program, demonstrates the futility of using the printed page alone to distill the creative process or the meaning in experimental art.

PAIR pairs select San Francisco Bay-area artists working in new media with Xerox researchers for free-form collaborations lasting a year or more. Today's PARC, it should be understood, is on a much shorter leash than its first incarnation. The emphasis is on understanding how knowledge workers use documents and on bringing new office technologies to market; the current director of Xerox PARC, John Seely Brown, defines innovation as "invention implemented" *(see "Field Work in the Tribal Office,"* TR *May/June 1998).* It's no surprise to read in *Art and Innovation,* then, that at PAIR's outset in 1993, "the researchers felt that their projects did not lend themselves to artistic interaction and that pairing would therefore be a time sink."

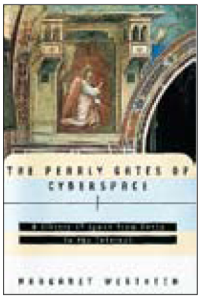
Much of the the book—the intent of which, according to editor Craig Harris, is "to reflect the process of the collaborations and to provide insights into the cultural setting"—records the artists' challenges and anxieties as they connected with researchers and learned to use PARC's technologies. The "PAIRings" did apparently result in some intriguing work, but in print the artists' notes on their videos, multimedia installations and performance art pieces inevitably come off as breathless, self-indulgent and overintellectual—in a word, "artsy." I imagine, for

example, that on a computer screen "Forward Anywhere," an "interactive hypernarrative" documenting an extended e-mail correspondence between novelist Judy Malloy and PARC scientist Cathy Marshall, is fun to explore. On paper, the interactivity is lost, and the authors' attempts to explain how interactivity molded the project and the process quickly grow wearisome.

When you put smart, creative people together in a hothouse atmosphere, interesting ideas happen almost automatically, as these two new books on Xerox PARC demonstrate. Exporting these ideas, they also show, is a far trickier proposition.

Dogs and Gods Both Welcome

THE PEARLY GATES OF CYBERSPACE:
A History of Space from Dante to the Internet
by Margaret Wertheim
W.W. Norton, 336 pp., $24.95



IN 1993, WHEN A NOW-FAMOUS *New Yorker* cartoon appeared with the caption "On the Internet, no one knows you're a dog," it was already a cliché that cyberspace is a magical place where the bodily limits and petty prejudices of the real world no longer hold. But the number of people who log on every day in search of like minds, novel experiences or safe sex continues to grow exponentially, proving that this is a cliché with staying power.

Margaret Wertheim offers an explanation for the Internet's appeal, and it goes way beyond the ideas of previous analysts such as MIT sociologist Sherry Turkle, whose 1997 book *Life on the Screen* interpreted the Net as a playground for our multiple selves. Cyberspace, Wertheim suggests, fills the spiritual vacuum Western science created when it demoted Heaven from a real celestial place—immaterial, yet inhabiting the same universe as ours—to a mere metaphor for the mystery of death.

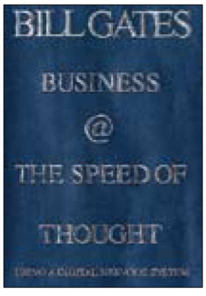
That may sound like quite a feat for an artifact that is nothing more, after all, than a tangle of telephone wires, transistors, TV screens and transfer protocols. But Wertheim makes a remarkably convincing case for her thesis, by showing just how closely Western theology and cosmology have been tied to changing conceptions of space. Her tour starts with the Hell and Heaven of *The Divine Comedy*. When Dante placed these realms deep within the Earth and above the stars, respectively, he wasn't being entirely fanciful, Wertheim asserts. God and sin, as the organizing principles of the medieval Christian cosmos, gave space an inherent "up" and "down," making the sky above the stars the logical place for virtuous souls to reside.

But when Copernicus, Kepler and Galileo smashed the crystal spheres of Ptolemaic space and showed that the "heavenly bodies" are mere matter—subject to the same physical laws that apply on Earth—it signaled hard times ahead for the Christian idea of the soul. In the modern scientific worldview, Wertheim observes, "the whole of reality is taken up by physical space, and there is literally no place within this scheme for anything like a spirit or a soul to be."

Clearly, however, billions still long to believe in an aspect of the self that exists apart from the body. Wertheim's notion, argued with style and intelligence, is that the shared worlds created by the denizens of chat rooms, Usenet newsgroups, graphical virtual realities, or text-based multi-user domains (MUDs) provide the closest thing this world has to offer to genuine out-of-body experiences. On the Internet, in other words, the spirit-self can finally spread its figurative wings. Both dogs and gods are allowed.

More Billboard Than Bible

BUSINESS @ THE SPEED OF THOUGHT:
Using a Digital Nervous System
by Bill Gates, with Collins Hemingway
Warner Books, 470 pp., $30



A SENSE-AND-RESPOND organization, according to a Harvard Business School collection of the same name *(reviewed in* TR, *May/June 1998)*, is a business literally wired to detect changes in customers' needs and to quickly launch new products or services that will exploit opportunity or avert disaster. Microsoft, one of the contributors' favorite examples, earned extra merit badges for its rapid rebound in the Internet browser wars of 1995-96. Now Bill Gates has decided to cash in on this cachet with a volume that exalts the electronic reflexes behind the success of Microsoft and other firms. (Gates' personal proceeds from the book, the dust jacket notes, will go to charity.)

Microsoft's secret, it turns out, is that it uses Microsoft software. Aside from Windows, Word, Excel, Explorer, et cetera, the company has built internal applications such as MS Sales for sales reporting; MS OnTarget for project accounting; MS Market for procurement; MS HeadTrax for tracking personnel changes; MS Reports for interfacing with expense, customer, contract and budget databases; and MS Invoice, a private Web site allowing contractors to submit invoices electronically. "We have infused our organization with a new level of electronic-based intelligence," Gates enthuses. Such infusions will no doubt be available to others as soon as Microsoft boxes the tools Gates advertises.

So how exactly did Microsoft's digital nervous system help it respond to what Gates calls "bad news on a colossal scale," the unexpected transformation of the Internet from an academic tool into a global commercial network? The impetus for a response "didn't come from me or from our other executives," Gates writes. It came from "a small number of dedicated employees who saw events unfolding. Through our electronic systems they were able to rally everybody to their cause."

Sounds impressive, until you realize the "electronic system" Gates is referring to is e-mail. Equally deflating, Microsoft's electronic senses apparently failed to sense that the company's marketing practices would provoke a federal antitrust suit. The future is undeniably digital, and Microsoft will no doubt profit. But *Business@ The Speed of Thought* is more like a billboard than a bible. ◊

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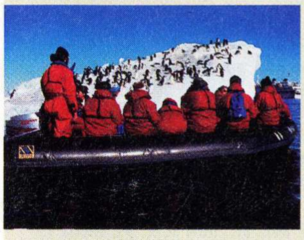

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Medicine's Manhattan Project

Wartime mass production made penicillin a panacea

ALEXANDER FLEMING'S 1928 DISCOVERY OF PENICILLIN IS one of medical history's most famous moments. But the original wonder drug languished in laboratories until a World War II research program that rivaled the Manhattan Project—at times literally—brought it to hospitals and battlefields.

By the summer of 1941, Oxford University researchers led by Howard Florey and Ernst Chain had shown that penicillin could cure people of deadly bacterial infections. But making the drug was difficult: The Oxford group started out growing the antibiotic-producing *Penicillium* mold in bedpans, and even resorted to collecting penicillin from treated patients' urine. Still, they amassed enough of the drug to treat only six patients. With bombs falling on Britain, Florey and a collaborator went to the United States for help.

A critical stop on their tour was the Department of Agriculture's Northern Regional Research Laboratory (NRRL) in Peoria, Ill. Quickly convinced of penicillin's importance, the NRRL researchers went to work. One of their key developments was submerged or "deep" fermentation, a way of culturing the mold within a liquid medium, rather than floating on top. Within a few years, penicillin producers abandoned the thousands of glass flasks or milk bottles needed each day for surface culture in favor of tank fermenters that held thousands of liters like those at Merck and Co.'s Rahway, N.J., plant shown above.

The NRRL also led the search for better-producing variants of *Penicillium*. They analyzed molds from cheese factories, kitchens and soil samples collected by Army pilots around the world. The best mold came from a cantaloupe found in a Peoria market. To this day, penicillin manufacturers use descendants of that strain.

The NRRL's early successes and the federal government's urging helped convince drug companies that large-scale production of penicillin was possible. Ten days after the Pearl Harbor bombing, several industry heads agreed to combine efforts with the government, the military, academia—and each other. Together, the hundreds of researchers at these organizations overcame numerous technical challenges under conditions of wartime scarcity, at times competing with Manhattan Project labs for equipment.

In 1944 the penicillin program paid off: The manufacturers had made enough of the drug to treat all the Allied wounded in the D-Day invasion of Normandy. The next year, penicillin production exceeded 6.8 trillion units—enough for everybody. ◊

***Technology Review* welcomes suggestions from readers for Trailing Edge.**
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FDA historian John Swann and the Candida Corporation's Richard Mateles, among others, helped with this story. Send a few paragraphs to:
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